NEW

THE STORY OF HUMANS

Discover the remarkable origins of our species

How our ancestors conquered the world

FROM THE MAKERS OF HOW IT WORKS

Digital Edition

FUTURE

FOURTH EDITION

Evolution • Innovation • Exploration

Welcome to THE STORY OF HUMANS

Join us on a journey through human history and explore how evolution and ingenuity shaped our species. From the first branches of the Homo family tree to the astonishing achievements our species are capable of today, discover how one super-smart bunch of apes became astronauts. Inside you'll learn why harnessing fire and crafting tools shaped our future, how we triumphed over our Neanderthal relatives, why the invention of agriculture changed history and how the most complex structure in the known universe – the human brain – develops. Read on to learn more about the fascinating past, present, and potential future of our species.


FUTURE

THE STORY OF HUMANS

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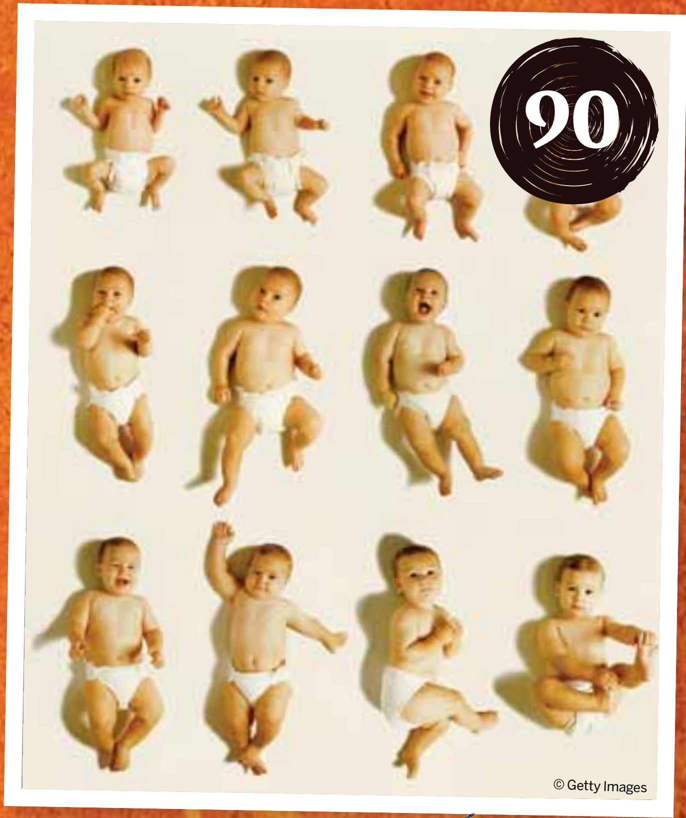

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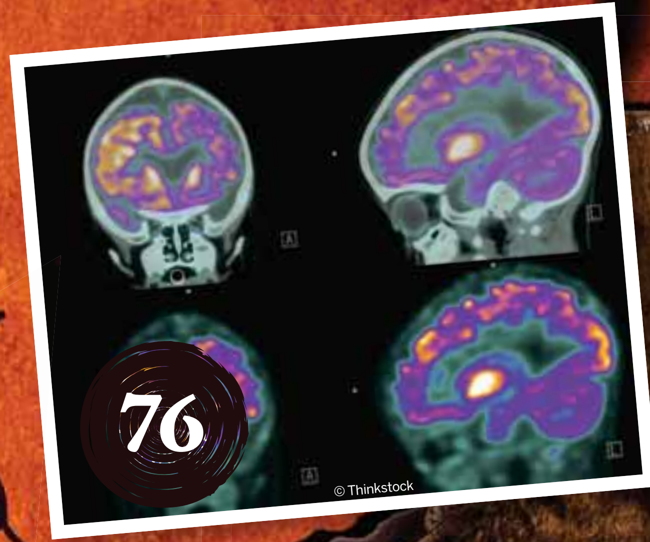

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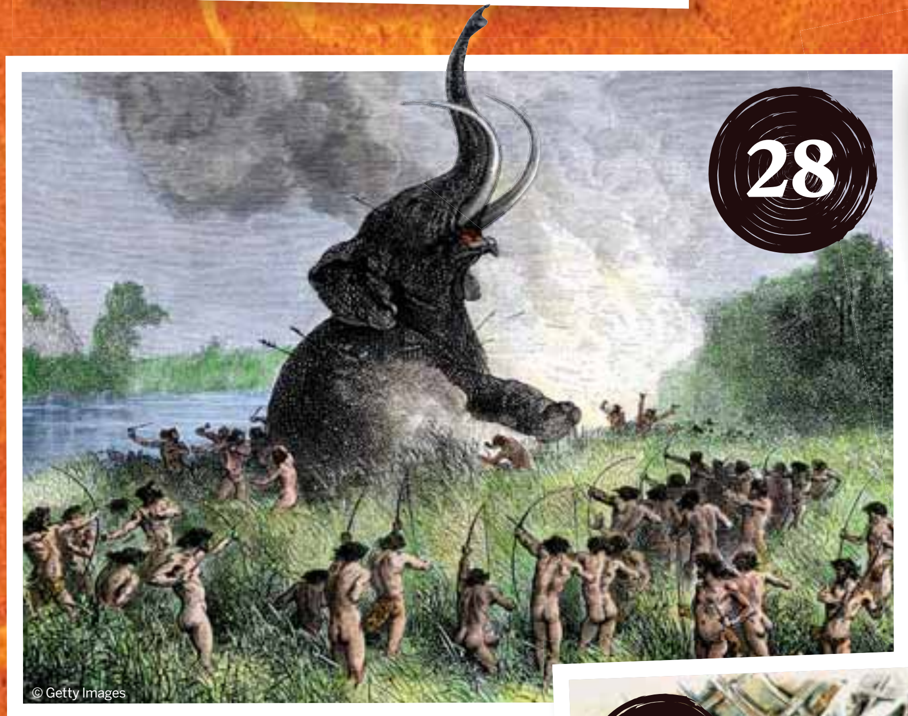
"Look back into our history and you'll find stories everywhere"



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What makes us human?

The future of humanity

EARTH IN A YEAR

Compress our planet's vast history into 12 months and humans saunter in just in time for the New Year's party

Words by **Victoria Williams**

JAN FEB MAR OCT NOV DEC

JANUARY 1

4.54 BYA
Earth is estimated to be about a third of the age of the universe. The Sun and planets formed from the cloud of dust and gas that comprised the young Solar System when gravity caused material to clump together.

JANUARY 4

4.51 BYA
The Moon was formed not long after the Earth. According to the most widely accepted theory it was created when Earth collided with another planet in a 'giant impact', sending debris into orbit.

MARCH 24

OCTOBER 1

1.2 BYA
At some point around a billion years ago a few organisms stopped reproducing by simply splitting in half and started to reproduce sexually with other members of their species.

NOVEMBER 23

470 MYA
The first plants to emerge on land resembled mosses and liverworts. They lacked roots and transport systems, relying on fungi to provide them with water and nutrients in exchange for some of the organic compounds they produced during photosynthesis.

NOVEMBER 30

400 MYA
Insects appeared at least 400 million years ago – possibly as early as 480 million years ago. Early species were restricted to crawling over land and plants, but one line went on to evolve wings and take to the air.

DECEMBER 12

240 MYA
Dinosaurs evolved from other reptiles and began to roam the Earth. When the planet's history is compressed into a year, they survived for just two weeks.

DECEMBER 31 23:59:27

2560BCE
Ancient Egyptians picked up their tools and started building the pyramids. These impressive structures served as tombs for pharaohs and their families.

DECEMBER 31 23:59:44

44BCE
Roman leader Julius Caesar was assassinated – stabbed by a group of senators who had conspired against him.

DECEMBER 31 23:59:52

1066
The Battle of Hastings took place. A victorious William the Conqueror claimed the throne as the first Norman king of England.

DECEMBER 31 23:59:55

1492
Christopher Columbus 'discovered' the Americas. He landed on an island in the Bahamas after a two-month sea voyage from Spain.

DECEMBER 31 23:59:57

1760
A surge in technological innovations kick-started the Industrial Revolution. This was a period of unprecedented growth in industry, manufacturing, economy and population.

DECEMBER 31 23:59:59

1969
On 20 July 1969, Neil Armstrong takes humanity's first steps on the Moon – a defining moment in the history of our species.

PRESENT DAY

Scientists believe that huge impacts between rocky bodies in the early Solar System created celestial objects like the Moon

APR

MAY

JUN

JUNE 22

3.5 BYA

Around 3.5 billion years ago, after asteroids had stopped raining down on the planet, Earth became less barren as life evolved. These organisms, each made up of a single cell, are the ancient ancestors of every species alive today.

2.4 BYA

Certain bacteria began to use sunlight to convert carbon dioxide and water into sugar – the same process used by green plants. Oxygen was released as a waste product, creating an oxygen-rich atmosphere that would later support animals with lungs.

Insects were flying around long before dinosaurs came onto the scene

JUL

AUG

SEP

200 MYA

Early mammals evolved – these were small, nocturnal shrew-like animals that hunted insects. Mammals stayed in the background until the extinction of the dinosaurs, after which they rapidly diversified and grew.

DECEMBER 15

175 MYA

The supercontinent Pangaea began to split apart. Carried in different directions by tectonic activity, the pieces would eventually become the modern continents.

DECEMBER 17

130 MYA

Plants first burst into bloom at least 130 million years ago. It could have been earlier, but because they were so delicate few ancient flowers were fossilised.

DECEMBER 22

~315,000 YEARS AGO

Homo sapiens – modern humans – evolved from another human-like ape. They lived alongside Neanderthals for thousands of years but eventually became the only remaining Homo species.

DECEMBER 31

23:24:00

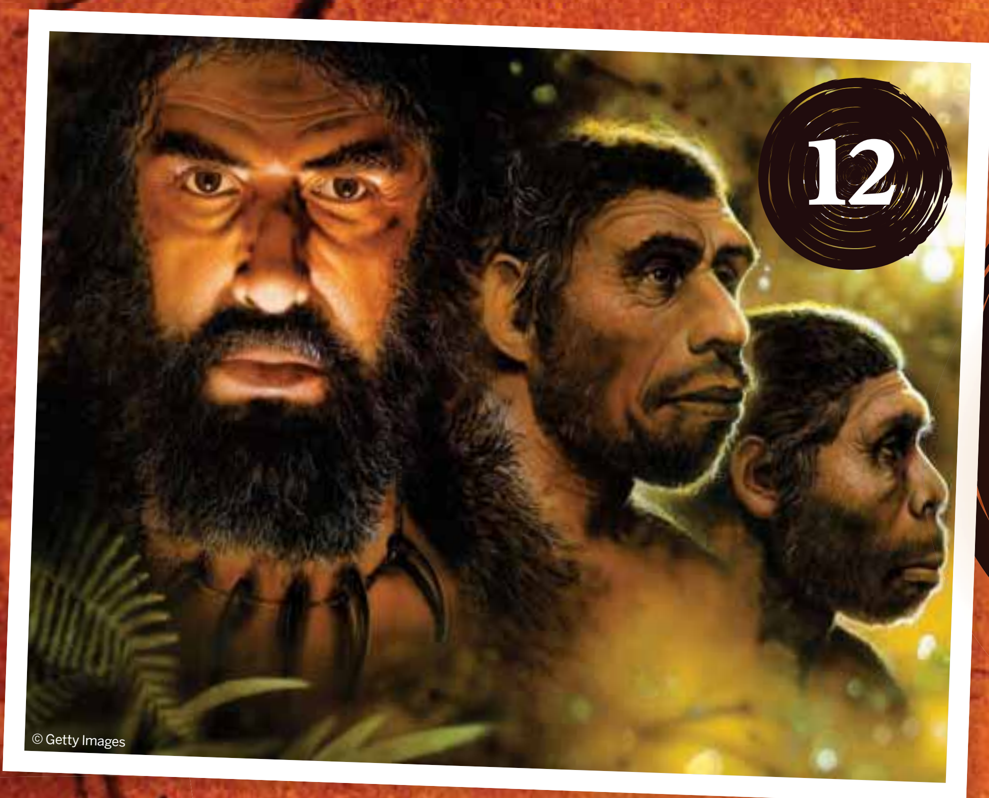
DECEMBER 26

68 MYA

Tyrannosaurus rex first appeared, measuring over 12 metres from head to tail. In this geologic year, the most famous of all the dinosaurs would only have six hours to stomp around and terrorise smaller creatures.

Relatively speaking, the pyramids of Egypt aren't ancient at all

EVOLUTION



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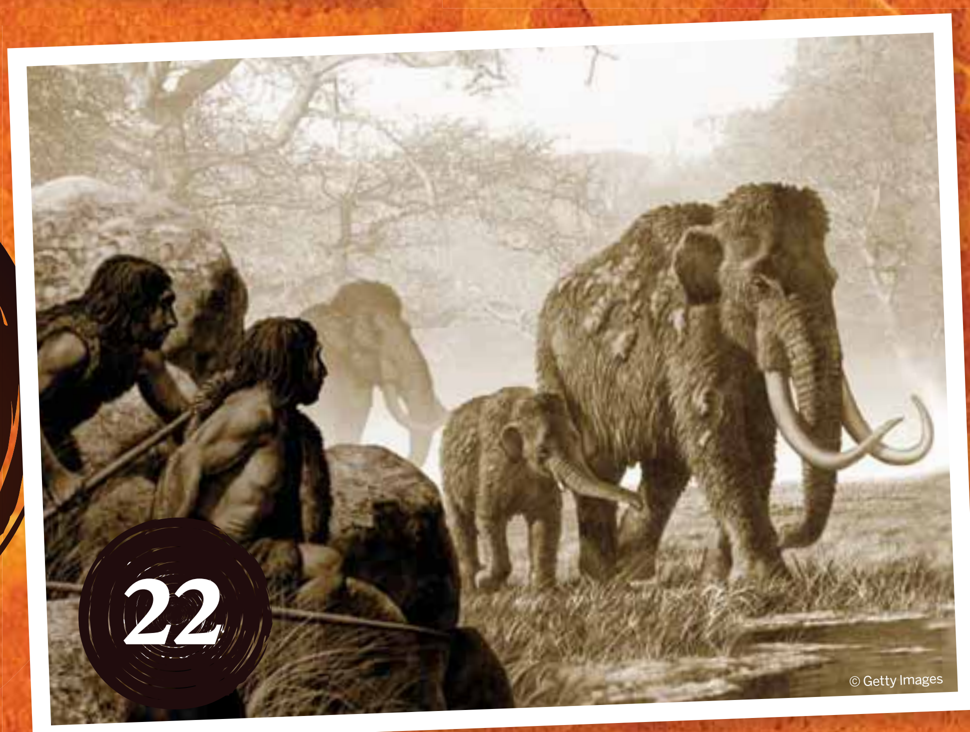
The story of humans

How our ancient ancestors crossed continents and conquered the planet

Neanderthals

Our human cousins were far more complex and advanced than we give them credit for



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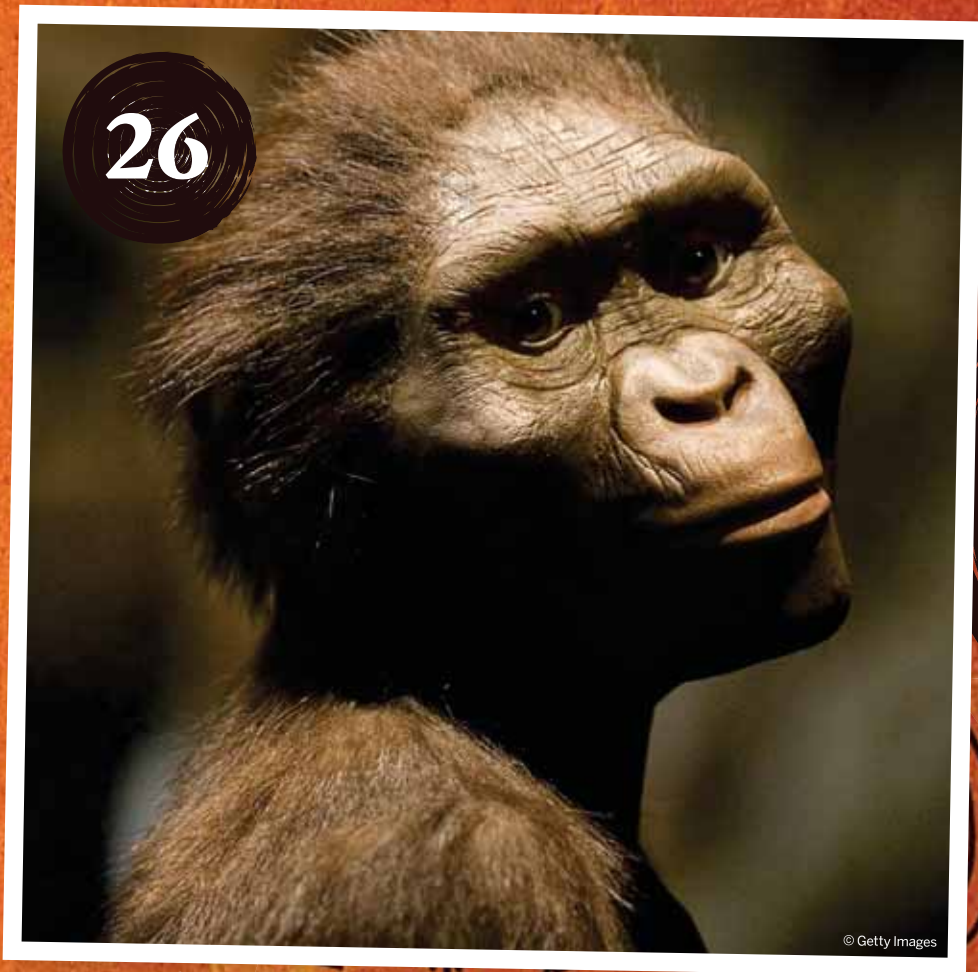
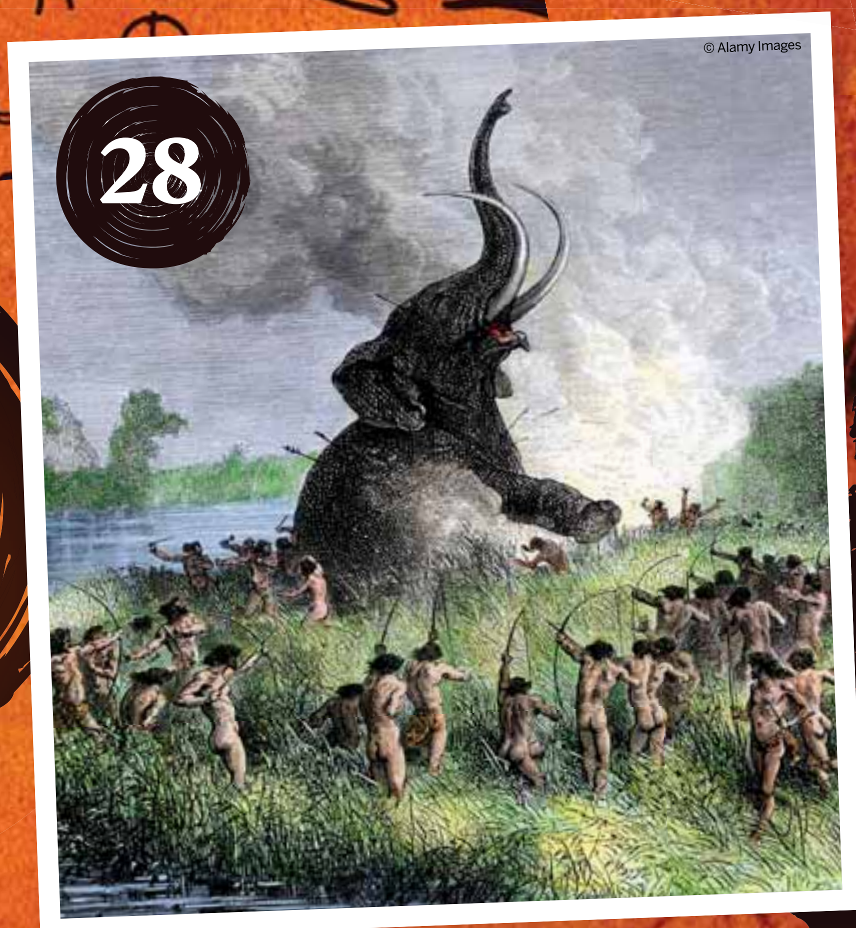


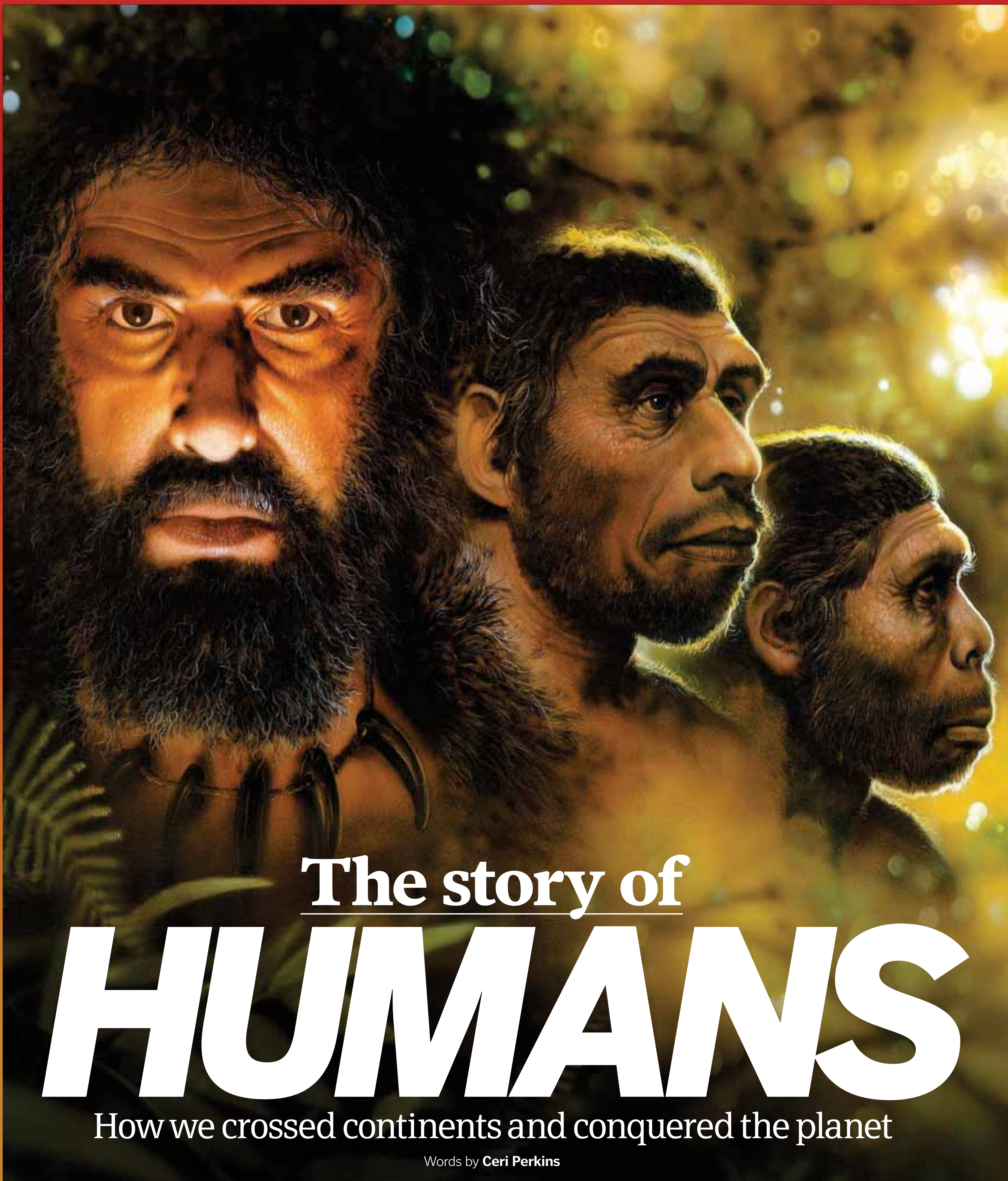
Who was Lucy?

Meet the grandmother of humanity: a 3-million-year-old ape that walked on two legs



Life as a hunter-gatherer

Find out how nomadic humans hunted and foraged for their next meal



The story of HUMANS

How we crossed continents and conquered the planet

Words by **Ceri Perkins**

In the iconic *March of Progress* illustration, human evolution is depicted as a single flowing process that begins with apes and ends with our modern selves. But in truth, our evolutionary past is a messier affair, involving an assortment of ancestors treading a multitude of paths that split, stumble and intersect in ambiguous ways.

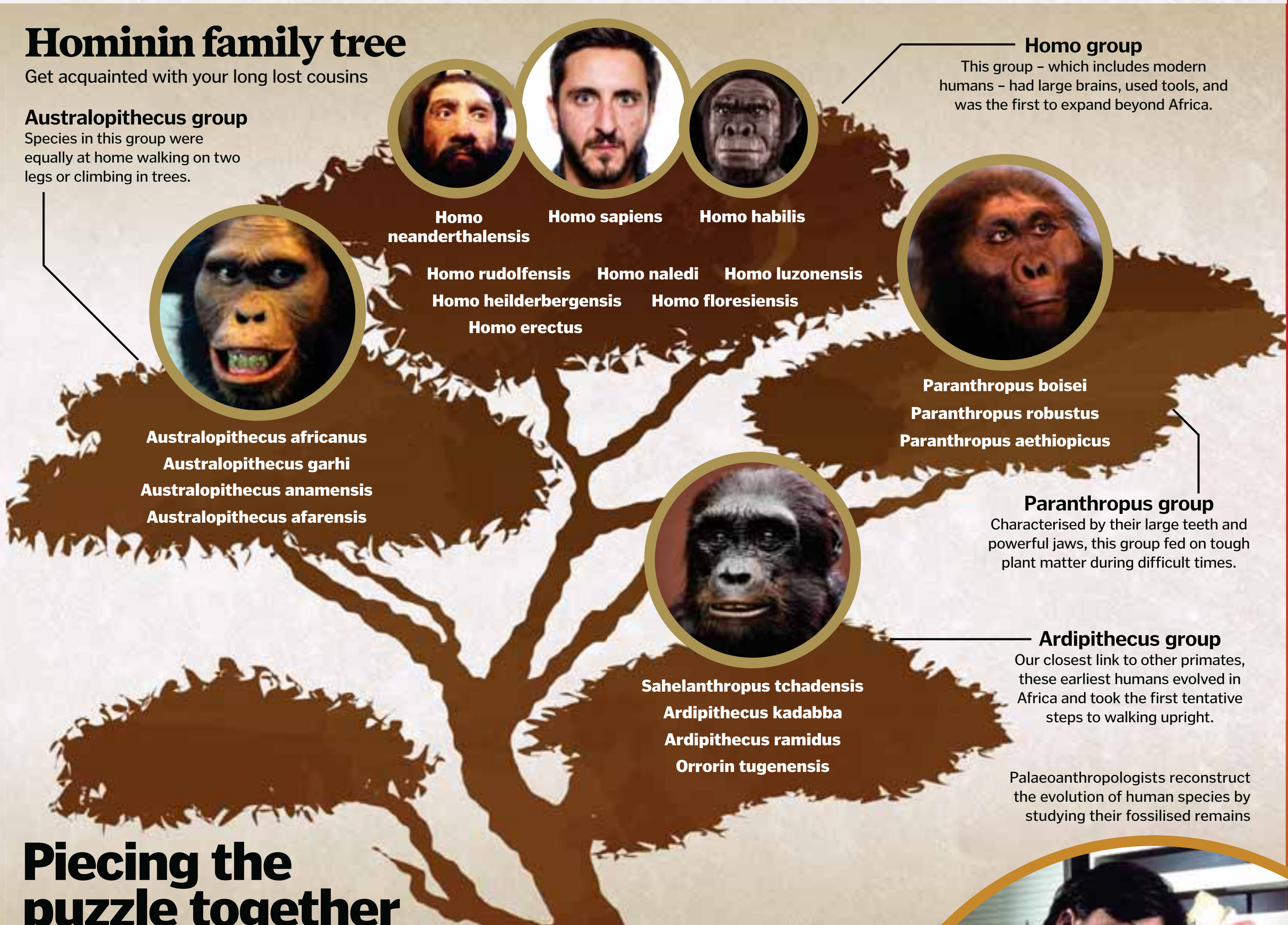
When we draw family trees, each end branch represents a distinct species – a grouping of individuals that are genetically similar enough to interbreed. New species evolve through the process of natural selection: environmental pressures favour some traits over others, which causes populations to gradually adapt or diverge in order to have a better chance of surviving.

Despite a fragmentary fossil record, scholars have traced the evolution of hominins – that is, the group of species including modern humans and our ancient bipedal ancestors – back more than 6 million years. But field scientists are still uncovering 'new' extinct hominins, meaning that our understanding of human evolution is itself constantly evolving.

While we know that modern humans and chimpanzees diverged from a common ancestor between 6 and 8 million years ago, scientists are still striving to find the earliest hominin and pin down the moment the two lineages split. Above all, they seek to answer the most fundamental question in human evolution: what sequence of events and adaptations occurred to transform apes into humans?

Hominin family tree

Get acquainted with your long lost cousins



Australopithecus group
Species in this group were equally at home walking on two legs or climbing in trees.

Homo group
This group – which includes modern humans – had large brains, used tools, and was the first to expand beyond Africa.

Paranthropus group
Characterised by their large teeth and powerful jaws, this group fed on tough plant matter during difficult times.

Ardipithecus group
Our closest link to other primates, these earliest humans evolved in Africa and took the first tentative steps to walking upright.

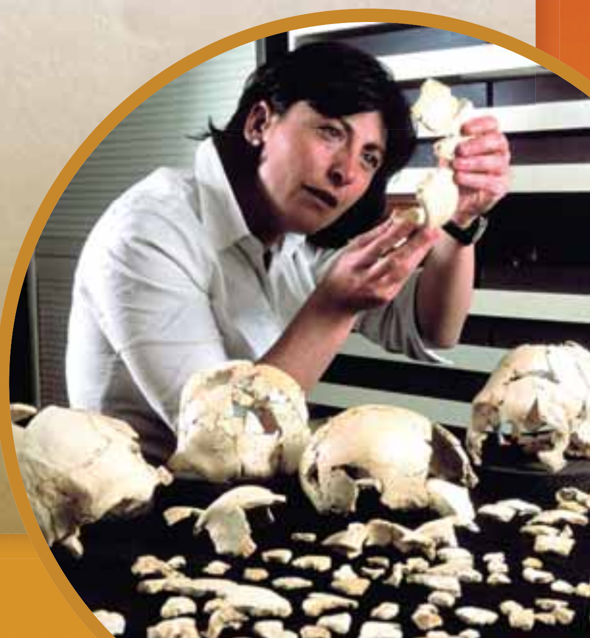
Piecing the puzzle together

Palaeoanthropologists are scientists who peer into our evolutionary past. As they try to piece together our family tree, their most important clues come from fossils – physical evidence of ancient hominins, like bones and teeth, which help to classify different species.

In order to reconstruct how species evolved, it is crucial to know how old these fossils are. However, the commonly used method of radiocarbon dating can only be used on specimens younger than 40,000 years old.

Instead, experts look at materials in close proximity to the fossils, such as the layers of rock they were discovered in. Careful study of local geology combined with chemical analysis allows fossils and artefacts within the layers to be dated.

In the last decade, DNA sequencing has revolutionised this field. Because genetic mutations happen at predictable rates and are passed from parent to child, fragments of ancient DNA can be compared to our own to reveal secrets about our ancestors' biology and behaviour.



Palaeoanthropologists reconstruct the evolution of human species by studying their fossilised remains

The Homo genus

What set our closest relatives apart from earlier human species?

Every human on the planet today is a member of one single species: Homo sapiens. Together with our extinct ancestors and closest relatives, we are part of the broader genus of Homo, whose members all share unmistakably human traits.

The Homo genus emerged somewhere around 3 million years ago in Africa, when the region was home to at least 11 species of hominin. The oldest Homo fossil – dated at 2.8 million years old – was a member of the species Homo habilis. Its name means 'handy man', as it is believed to be the first hominin that used stone tools. Although it retained many of the ape-like body features of earlier Australopithecus, its brain was much larger.

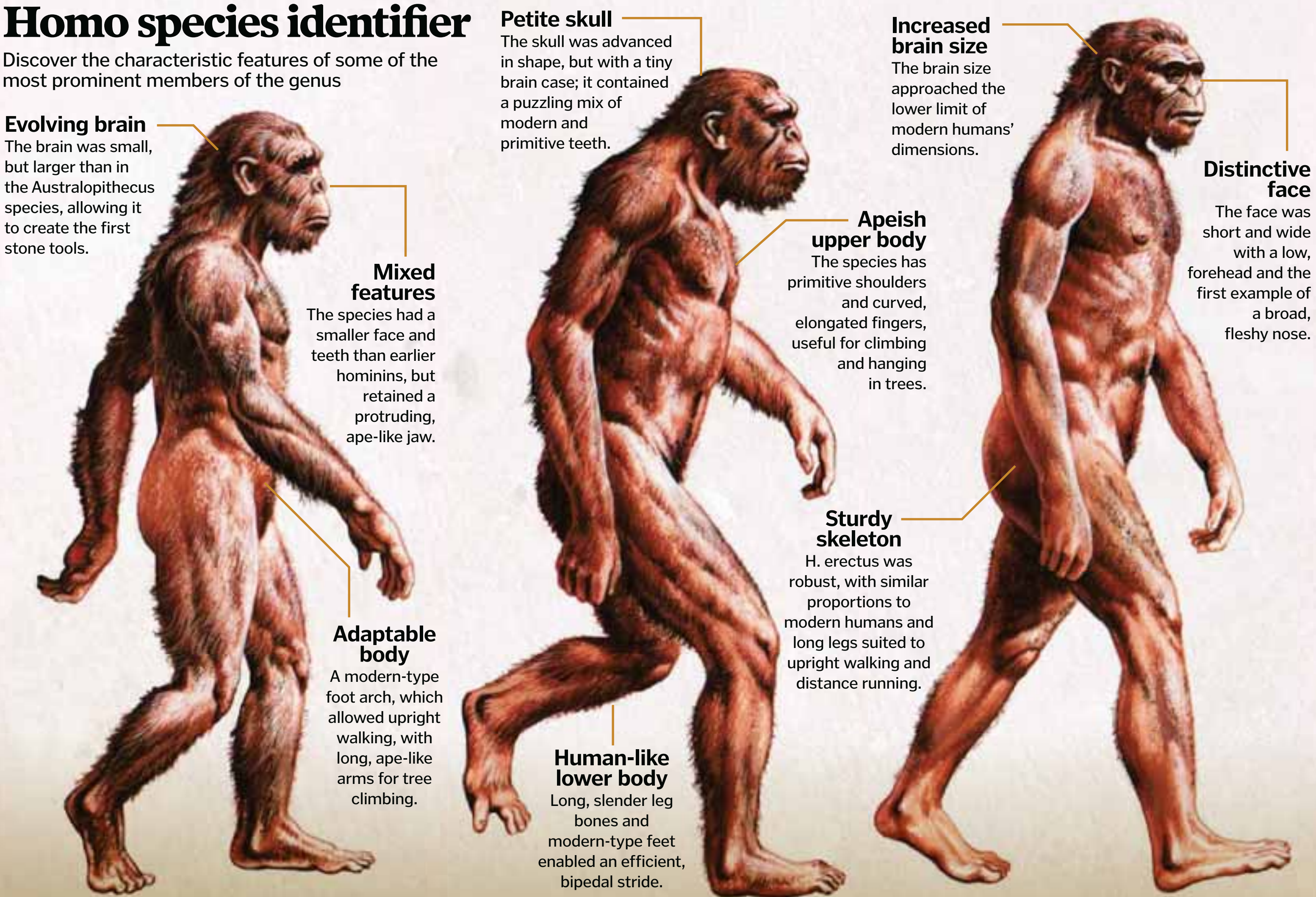
Tool use and brain size are two of the defining characteristics of the Homo genus. The third is an upright skeleton that enables walking on two feet. Together these changes gave an evolutionary edge in exploiting the environment, solving problems, and journeying over long distances.

Our own species is thought to have evolved 200,000 years ago from the strong, athletic Homo heidelbergensis. They in turn evolved from Homo erectus – one of the most successful hominins in history, surviving for 2 million years.

For a long time, scientists have argued over whether H. sapiens evolved within Africa before spreading around the world (the Out of Africa hypothesis) or evolved simultaneously in many locations (the multiregional hypothesis). Recent studies of DNA suggest we descend from a single population living 150,000 years ago, which heavily supports the Out of Africa theory.

Homo species identifier

Discover the characteristic features of some of the most prominent members of the genus



HOMO HABILIS
Height: **1.1-1.2m** Weight: **30-36kg**
Average brain size: **610cm³**

HOMO NALEDI
Height: **Approx 1.5m** Weight: **Approx 45kg**
Average brain size: **560 cm³**

HOMO ERECTUS
Height: **1.45-1.8m** Weight: **40-68kg**
Average brain size: **1,050cm³**

HUMAN HISTORY TIMELINE

6-8 MILLION YEARS AGO
Divergence of human and chimpanzee lineages from the last common ancestor.

6-7 MILLION YEARS AGO
Sahelanthropus tchadensis develops small canines, distinguishing it from apes.

6 MILLION YEARS AGO
Sahelanthropus walks upright, becoming the first bipedal hominin.

2-6 MILLION YEARS AGO
Brain size undergoes a slow, steady increase as bipedalism and tool use proliferate.

Did humans and Neanderthals interbreed?

In 2010, scientists announced a startling new twist in the human evolution story. Recently extracted fragments of Homo neanderthalensis DNA showed that 50,000 to 60,000 years ago – when they overlapped with modern humans in the Levant as they were flowing towards Eurasia – the two species occasionally interbred. In fact, the genome of everyone alive today who is not of African descent contains somewhere between one and four per cent Neanderthal DNA.

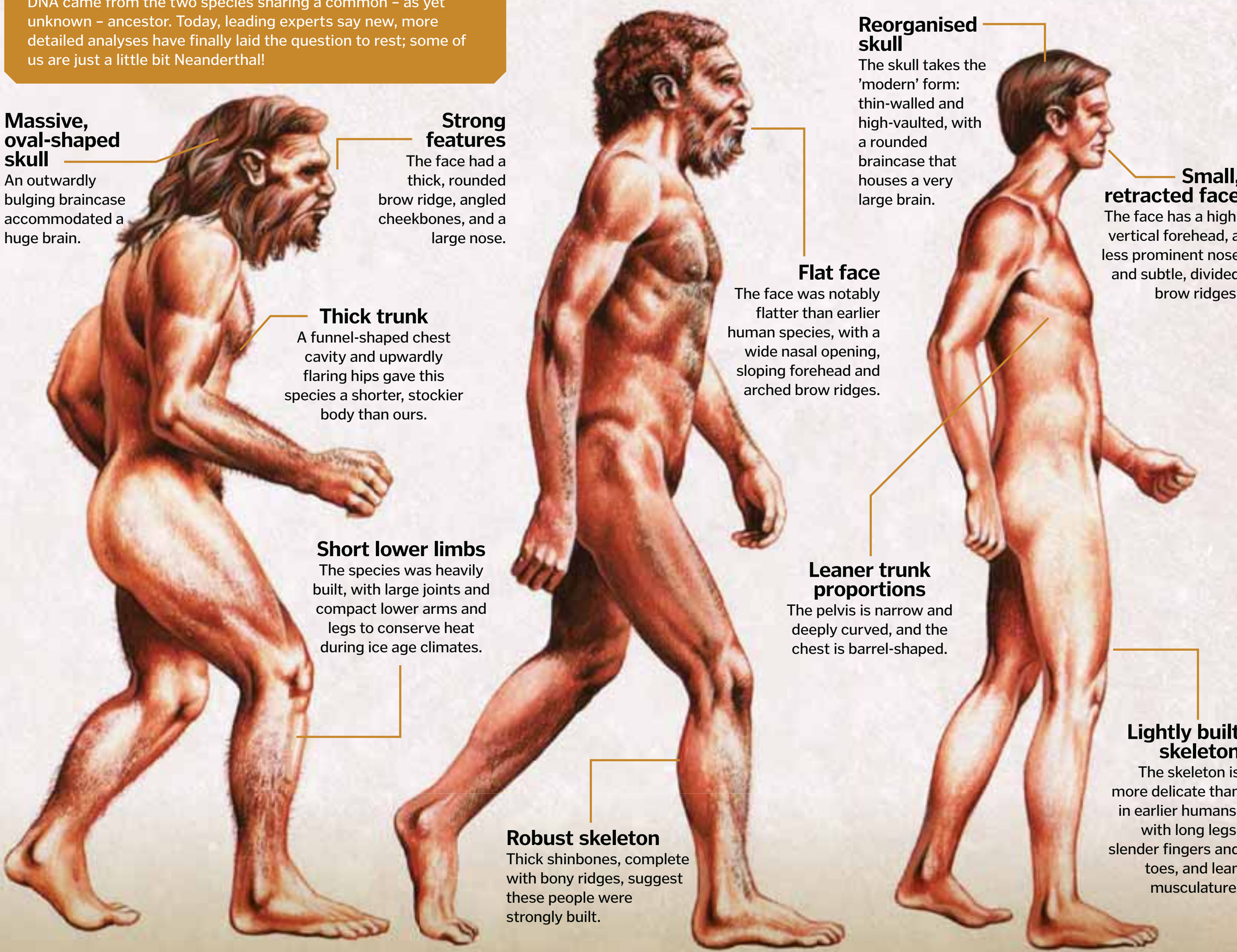
Neanderthals are our closest cousins, having also evolved from H. heidelbergensis. Although it is sometimes possible for two genetically similar species to have offspring together, some scientists were initially sceptical. They argued that the shared DNA came from the two species sharing a common – as yet unknown – ancestor. Today, leading experts say new, more detailed analyses have finally laid the question to rest; some of us are just a little bit Neanderthal!

Opposable thumbs

The grasping hands of our primate ancestors evolved as an adaptation to life in the trees. Opposable thumbs – which are able to move around and touch the other fingers – and flat fingertip pads both help tree-dwellers to grab on to branches as well as hold and manipulate small objects.

Our modern thumb has changed little since the last common ancestor of humans and chimpanzees. It is longer, compared to finger length, than any other primate's thumb, giving both strength and precision. This helped our ancestors gather a wide variety of foods and eventually develop tools.

An opposable thumb enables the hand to grip with strength and dexterity



HOMO NEANDERTHALENSIS

Height: **1.5-1.6m** Weight: **54-65kg**
Average brain size: **1,420 cm³**

HOMO HEIDELBERGENSIS

Height: **1.6-1.8m** Weight: **51-62kg**
Average brain size: **1,270cm³**

HOMO SAPIENS

Height: **1.6-1.8m** Weight: **62-78kg**
Average brain size: **1,350 cm³**

4 MILLION YEARS AGO
Human ancestors are mostly bipedal, but are also still comfortable in trees.

3-3.5 MILLION YEARS AGO
Many species of Australopithecus thrive within Africa.

3.3 MILLION YEARS AGO
Infant growth rate slows and starts to resemble that of modern humans.

2.8 MILLION YEARS AGO
The earliest known member of the Homo genus – Homo habilis – emerges in Africa.

Tools and development

How physical adaptations and new skills helped advance human species

Thrusting spears gave Neanderthals the new predatory edge to hunt large prey

Four major development trends separate humans from apes: terrestrialism, which is the move from tree-dwelling to ground living; bipedalism, the shift from moving on all fours to walking upright on two legs; encephalisation, which is an increase in brain-to-body mass ratio; and civilisation – a catch-all that includes social organisation, technological thought, communication and culture.

Separating cause from effect in these areas is tricky and experts disagree over the order in which they unfolded. But climate science offers some of the most compelling evidence for where it all started.

Beginning around 10 million years ago, Africa's climate altered profoundly from lush tropical forests to sparse, open grassland. As food sources became more thinly distributed, walking on two legs would have enabled early humans to forage over long distances and even carry provisions for later. With reduced vegetation cover, standing upright would also have helped keep their bodies cool by reducing the exposed skin surface area, and moving more of the body up into the breeze and away from the hot earth.

Picking apart the other developments is more challenging. In particular, it isn't clear what spurred the expansion of the human brain. Mental skills perhaps became more important as a result of increasingly complex social interactions or the demanding technological thought required to produce stone tools. On the other hand, brain enlargement may only have been triggered once easily digestible, energy-dense food was available on a regular basis – in other words, after humans had figured out how to procure and cook meat. Homo species' digestive tracts then became shorter, freeing up energy for larger brains and bodies.

Tool-making became more systematic and the products more uniform; experts speculate that these increasingly ordered cognitive processes eventually led to organised language, symbolic thoughtand creative expression.

"Humans have been using tools for at least 3 million years"

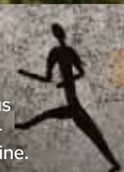
Lethal weapons

Traces of glue – perhaps tree sap or tar – found on Neanderthal-crafted stone points suggest that they were once attached to wooden shafts. Lashed in place with plant fibres, sinew, or leather, these would have made handsome spears, allowing Neanderthals to hunt larger prey from a safe distance, perhaps in cooperative groups.

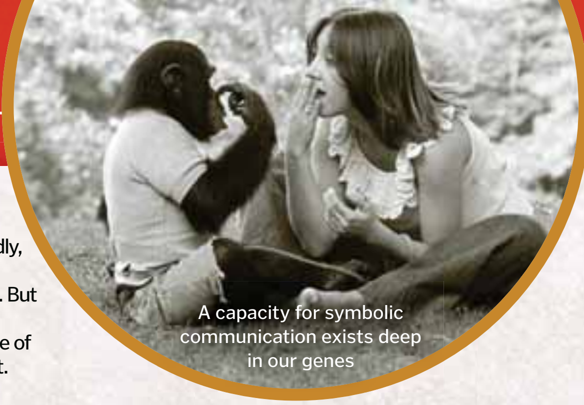
2.6 MILLION YEARS AGO
The dawn of technology: hammerstones and cores are used to produce sharp flakes.

2.6 MILLION YEARS AGO
Stone tools give access to new foods, including meat from large animals.

2.5 MILLION YEARS AGO
Australopithecus africanus develops modern, shock-absorbing curve in lower spine.



~2 MILLION YEARS AGO
Tools and food are transported to favoured resting and eating spots.



A capacity for symbolic communication exists deep in our genes

Culture

How did early humans make sense of their world? Sadly, fossils are silent on the subject of culture – language, rituals, music and other forms of symbolic expression. But shell beads made in Africa 100,000 years ago and 40,000-year-old cave drawings in Europe are evidence of our ancestors' impulse to create, express and connect.

40,000-year-old cave painting of a giant deer, in Lascaux, France

Communication

Many species communicate, but full language – with rules for combining sounds and words – appears to be uniquely human. One reason for this is that humans differ from most other primates in the way our larynx – or voice box – sits low in the throat. This allows us to shape sounds into speech, using our lips and tongues.

Precisely when and where language originated is unknown. The descended larynx evolved around 300,000 years ago, but experts believe spoken language only appeared in the last 100,000 years, probably developing out of a more basic 'proto-language' comprised of gestures and body language in addition to simple sounds.

Cooperation

When we work together cooperatively, we tend to achieve more in less time and with less effort. The same was true of our ancestors. By banding together, they could bring down larger animals in the hunt, forage a greater variety of foods, distribute tasks, defend resources and better protect the group from predators.

Early humans learnt to cooperate to bring down large prey

Brain size

In most mammals, brain size is proportional to body size. Most primates' brains exceed this ratio, but around 2 million years ago, our ancestors' brains started growing even larger. At the same time the brain was reordered, favouring the growth of some regions, such as those used for learning, over others, like those that govern smell.

Problem solving

As brain size and complexity increased, early humans became better equipped to tackle problems using logic and creativity. From tool-making to crossing continents to caring for the old and weak, it was this ability to interact with one another and the environment in novel ways that helped our ancestors survive in an unpredictable world.

Fire

Harnessing fire was a turning point in human history, but the evidence for how and when it happened is sparse and hotly contested.

Charred bones and ash suggest Homo ergaster interacted with fire in Africa as early as 1.5 million years ago, but whether the fires were wild or intentionally lit is a mystery. Better evidence of controlled use appears around 800,000 years ago; clusters of scorched tool-making debris, burned seeds, and wood mark more than a dozen early hearths across a site at Gesher Benot Ya'aqov in Israel.

Campfires not only provided warmth and protection from night-time predators; they also enabled food to be cooked, making it more digestible, and potentially influencing human brain evolution.

Tools of the age

Modern humans and our ancestors have been using tools for at least 3 million years. As intelligence increased, the tools that humans made became more sophisticated and specialised. Equipment for hunting, stripping animal carcasses and breaking open bones heralded an expansion in the ancient hominin diet, making more energy available for larger bodies and bigger brains.

Simple tools

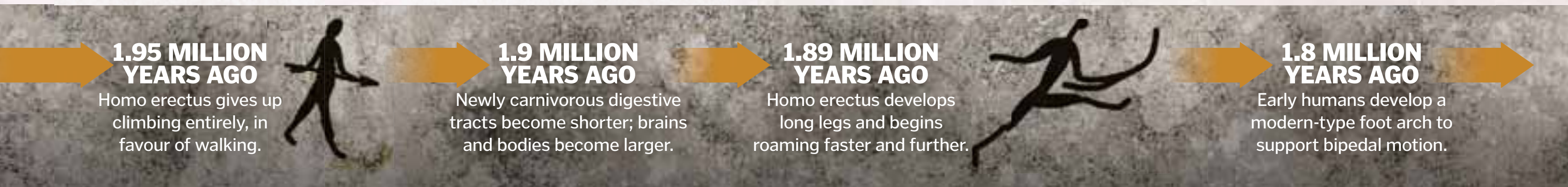
Around 2.6 million years ago, early humans learnt to strike one stone with another to remove sharp-edged flakes. These simple tools represent a major evolutionary advance – the first technological thought. Toolmakers had to plan, learn from their mistakes, and select appropriate materials.

Refining the design

By 300,000 years ago, toolmakers understood how to prepare a stone 'core' so that flakes knocked from its surface with a single blow would have long, clean cutting edges. These could be refined for different purposes by tapping smaller flakes off one or both sides.

Intricate devices

Around 50,000 years ago, humans living in Ice Age Europe began working bone, ivory and antler into intricate and specialised tools including needles, spear tips, fishhooks and harpoons. These materials are awkward to work with, and the tools are a testament to the manual dexterity and mental acuity of their makers.



1.95 MILLION YEARS AGO
Homo erectus gives up climbing entirely, in favour of walking.

1.9 MILLION YEARS AGO
Newly carnivorous digestive tracts become shorter; brains and bodies become larger.

1.89 MILLION YEARS AGO
Homo erectus develops long legs and begins roaming faster and further.

1.8 MILLION YEARS AGO
Early humans develop a modern-type foot arch to support bipedal motion.

How we conquered the planet

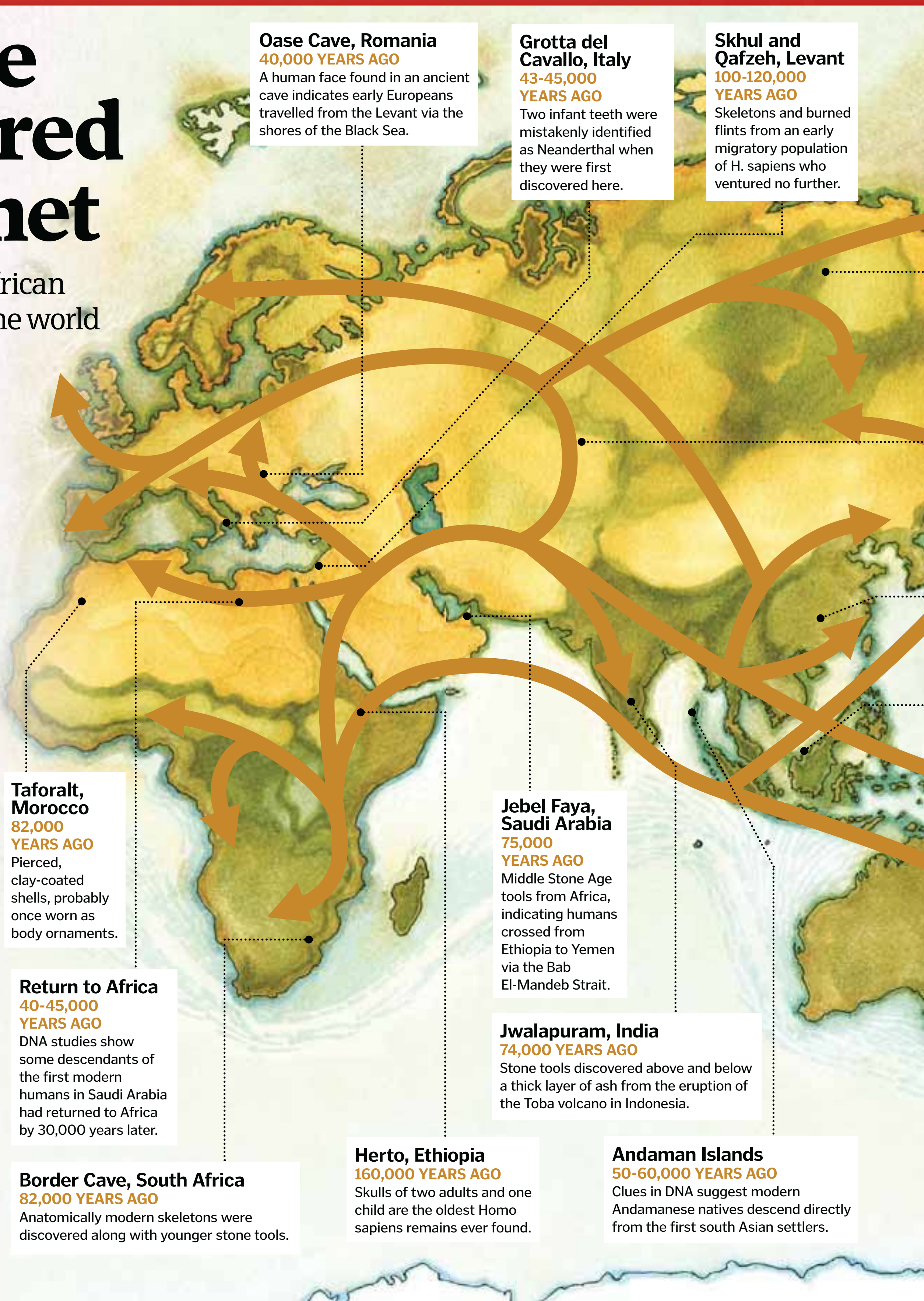
Humans went from African natives to citizens of the world

In our brief 200,000 years on Earth, Homo sapiens – unlike any of the human species before us – has managed to colonise the entire globe. But we were not the first to venture beyond Africa. Some of our ancestors took those initial steps at least 1.8 million years ago.

The first waves of adventurous hominins travelled east towards Asia, before eventually moving west and north into Europe. Homo erectus spread throughout Asia, reaching as far south as Java, and Homo heidelbergensis dispersed through both Asia and Europe.

As for our own species, all evidence suggests that we lived in Africa for the first 100,000 years of our 200,000-year existence. After a shaky first migratory attempt, it was another 30,000 years before we struck out again. This time marked the start of a mass exodus; Homo sapiens spread rapidly to all continents except Antarctica within 50,000 years, making us one of the most invasive species the world has ever known.

Why the itchy feet? Some scientists think we simply followed the roaming animals we ate; certainly other large predatory species made similar territorial expansions alongside us. Other experts hold the more romantic view that wanderlust is simply part of what makes us human.



1.8 MILLION YEARS AGO
Homo erectus becomes the first hominin to venture beyond Africa.

1.6 MILLION YEARS AGO
Neanderthals invent a hand axe – the first tool with well-defined form.

1.3 MILLION YEARS AGO
The Homo genus first spreads to Europe.

800,000 YEARS AGO
Early humans start to control fire and build hearths.

Homo sapiens goes global

Evidence from fossils, artefacts and DNA tells a compelling migration story

Siberia
43,000 YEARS AGO
Ancient tools reveal the first arrivals to inland Asia journeyed from the Middle East, over the Asian steppes.

Tianyuan Cave, China
40,000 YEARS AGO
The oldest securely dated modern human skeleton in China.

Central Asia
60,000 YEARS AGO
DNA analyses reveal complex lineages and multiple waves of colonisation.

Niah Great Cave, Borneo
40,000 YEARS AGO
'Deep skull' – one of several Homo sapiens remains found in this area – belonged to a 15-year-old girl.

Arnhem Land, Australia
55,000 YEARS AGO
The Malakunanja II rock shelter is the earliest evidence of human occupation in Australia.

Lake Mungo, Australia
40,000 YEARS AGO
Fossilised skeletons of a 50-year-old man and his cremated wife.

The Bering Land Bridge

We know from archaeological evidence that humans had made it to the Americas by at least 15,000 years ago. But looking at the world map, it's hard to fathom what feats of ingenuity and endurance they had to perform to travel from the Old World to the new. Even at their closest point, the frozen wastelands of Siberia and northern Alaska are separated by 85 kilometres of frigid ocean waters known as the Bering Strait.

But towards the end of the last Ice Age, around 20,000 years ago, monumental continental glaciers locked up so much of the Earth's water that sea levels were almost 100 metres lower than they are today. A broad swath of exposed land connected northeast Eurasia with northwest America. The first of many waves of immigrants are believed to have journeyed into North America via this 'land bridge', perhaps even living for a time in the now submerged province known as Beringia.

Clovis, USA
13,500 YEARS AGO
The earliest large settlement in North America, although evidence is mounting that humans arrived 2,000-3,000 years earlier.

"Humans are one of the most invasive species the world has known"

The land of Oz

Unlike their cousins in the Northern Hemisphere, the first inhabitants of Australia indisputably undertook journeys by sea. At the peak of the Ice Age, low sea levels meant Australia, Tasmania and New Guinea formed a single continuous landmass. But even then, the journey from Southeast Asia would have necessitated an eight-stage island hop that ended with an almighty 87-kilometre voyage across the Timor Straits.

No evidence of the Australian pioneers' seagoing vessels survives, and we can only speculate about what drove them to strike out for lands unseen. But strike out they did, and we see evidence of their successful arrival beginning around 50,000 to 60,000 years ago.

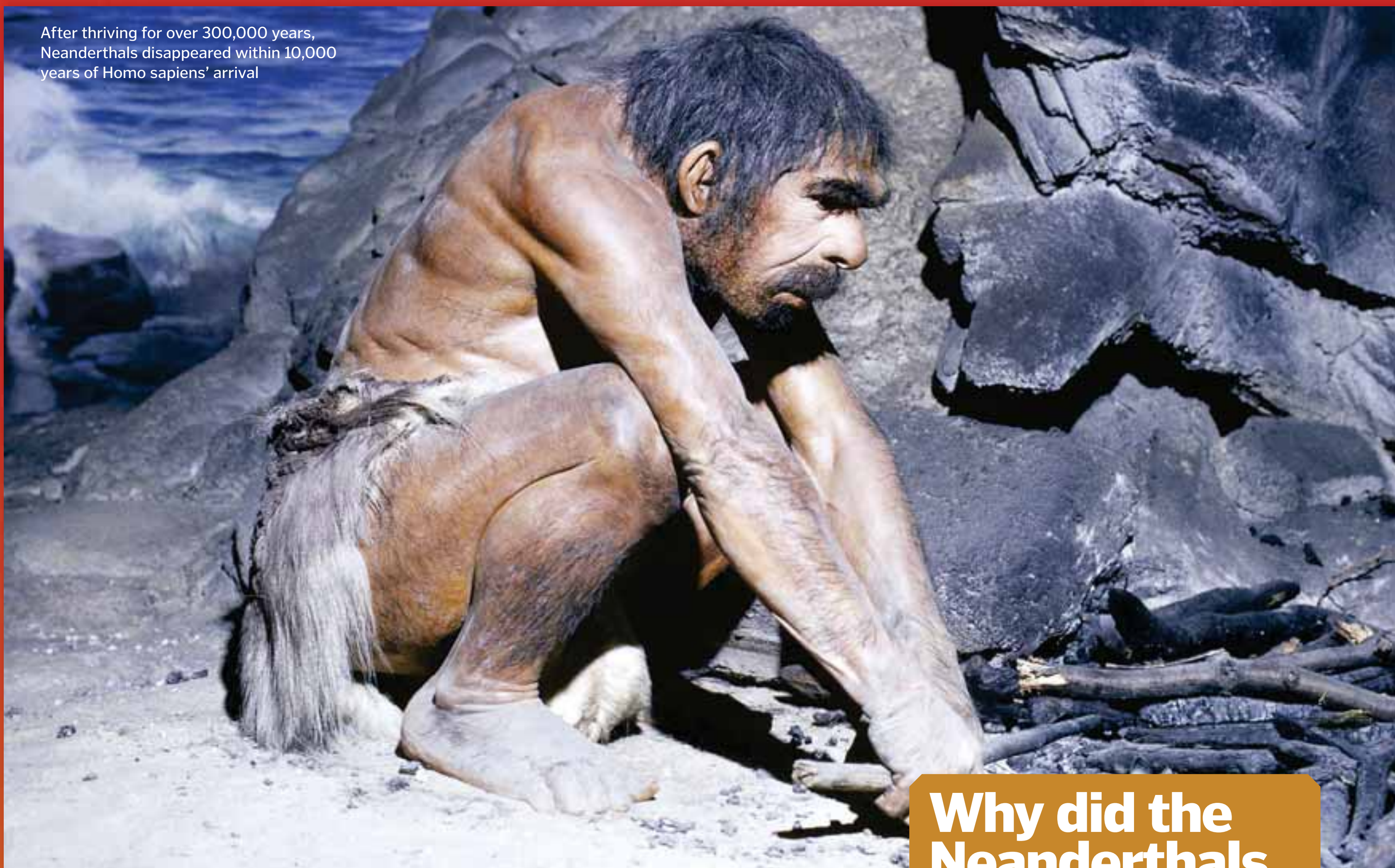
Monte Verde, Chile
15,000 YEARS AGO
Hearths, wooden structures and pollen from distant medicinal plants suggest a swift coastal migration by boat.

200,000-800,000 YEARS AGO
Dramatic climate change spurs rapid evolution of larger, more complex brains.

400,000 YEARS AGO
Wooden spears are used to hunt large animals from safer distances.

400,000 YEARS AGO
Shelters are constructed to protect families or social groups from predators and elements.

300,000 YEARS AGO
Toolmakers produce long, clean blades by striking stone cores.



After thriving for over 300,000 years, Neanderthals disappeared within 10,000 years of Homo sapiens' arrival

Surviving adversity

How modern humans overcame threats and evaded extinction

After over 6 million years of human evolution, Homo sapiens is the only species left standing. What is the secret to our success? Scientists believe it lies in our adaptability, our capacity for abstract thought and our ability to cooperate.

Indeed, no other animal species has adapted to as wide a range of habitats and such divergent pursuits as modern humans. As successive waves flowed out of Africa and dispersed throughout the world, we learned in each new place how to find and eat local food and to survive different climate conditions.

We could not have done this without technological ingenuity, nor without the cultural transmission of ideas – the ability to mimic one another, communicate concepts, and learn new skills. This allows the work of the most skilled or intelligent to benefit entire populations, instead of forcing each new generation to re-invent the wheel.

These characteristics made us resilient in the face of change. During the Ice Age winters of 15,000 years ago, for example, modern humans in eastern Europe came up with clever ways to cope with the cold. By sewing clothes from animal hides, building shelters from mammoth bones, preserving dwindling food supplies in the permafrost and using fire to keep warm, they were able to ride out the tough times together and ensure the survival of the species.

Why did the Neanderthals die out?

Between 35,000 and 45,000 years ago, modern humans spread throughout Europe, while the Neanderthals, present since over 250,000 years earlier, mysteriously disappeared. Many scientists suspect the two events are closely linked, and argue that Homo sapiens out-competed their close cousins for resources and perhaps even actively attacked them.

Others wonder whether the narrow Neanderthal gene pool might have been to blame. Some studies suggest that the Neanderthal population never grew bigger than a few thousand individuals. The lack of genetic diversity and small population size would have made them vulnerable to infections, radical shifts in the environment and natural disasters.

250,000 YEARS AGO
Pieces of pigment are used as chunky crayons to communicate with symbols.

195,000 YEARS AGO
Homo sapiens evolves in Africa during a time of dramatic climate change.

160,000 YEARS AGO
Homo sapiens collects and cooks shellfish on the southern shores of Africa.

130,000 YEARS AGO
Modern humans exchange resources over long distances.

A thriving species

How soil, society and science elevated modern humans

The moment when modern humans transitioned from merely surviving to convincingly thriving happened somewhere around 12,000 years ago, coinciding with the advent of agriculture.

For millions of years leading up to this time, early and modern humans alike were preoccupied with foraging, hunting and scavenging food. But once we discovered that we could control the growth and breeding of certain plants and animals, we quickly became farmers and herders.

As these practices gained momentum, settlements began to form around them. These grew from villages to towns to cities as food became more plentiful. Within them, the human population began to explode, eventually reaching levels where we were unlikely to be wiped out by anything less than a global catastrophe.

Cities became the focus of social interaction, idea exchange and technological innovation. The ballooning population allowed knowledge and creative expression to flourish, as individuals were able to specialise and learn from each other.

Over centuries and millennia, the rate of progress has continued to accelerate and innovations – from the printing press to the Internet, from surgery to vaccines, from the wheel to global air travel – continue to make our lives longer, safer and more rewarding.

Humanity's vast accumulation of medical expertise keeps us healthier than ever before

Where are we headed?

Of course, the story of humans is not over. Pressures of diet and disease, as well as our increasingly globalised lifestyles, continue to influence our genetic trajectory. In fact, some scientists think human evolution is accelerating. So what does our future hold?

For the first time in history, genetic engineering may soon give us direct influence over our own or our children's genes. But superhuman bodies will be useless if we continue to neglect the planet that sustains us. Despite our miserable environmental track record, we have the unique ability to comprehend the future consequences of our actions; the question remains whether we can learn to look beyond our immediate, individual interests.

If the planet can't meet the needs of the heaving population, we might eventually have to turn our gaze outwards. Colonisation of space might even result in new species of humans developing as populations are isolated by distance and interbreeding becomes impossible.

Below: Throughout history, humans have followed the urge to venture into the unknown

"The ballooning population allowed knowledge and creativity to flourish"

100,000 YEARS AGO
The first evidence of an intentional burial with ritual elements.

70,000 YEARS AGO
The major dispersal of Homo sapiens beyond Africa begins.

40,000 YEARS AGO
Modern humans create the first permanent drawings in Europe.

12,000 YEARS AGO
Agriculture begins to transform Earth's landscapes, first locally and then globally.

MEET THE NEANDERTHALS

These extinct humans are often portrayed as being barbaric, savage and primitive. But there's growing evidence that they were complex, caring individuals with a taste for jewellery

Words by **Dr Helen Pilcher**

Neanderthals had it tough. For over 150,000 years they lived in basic shelters, hunting mammoths and slogging it out against the brutal, ever-changing elements wearing little but simple furs and skins. Battered by their harsh, unforgiving lifestyles, few survived into their thirties. Then around 30,000 years ago, they went extinct. But if that wasn't bad enough, their final insult is still playing out to this day.

Call someone a 'Neanderthal' and you're inferring they're a dim-witted thug. The term conjures up images of unkempt cavemen with more brawn than brains. But the evidence stacking up paints a different picture, and it means that Neanderthals have very much been misunderstood.

As it turns out, we're all a little bit Neanderthal anyway. In 2014, researchers confirmed that Neanderthal DNA is hiding in people alive today. A staggering 20% of the archaic genome lives on in modern humans, and 2-4% of the genetic information in a non-African person comes from Neanderthals. This is an heirloom from sexual liaisons between them and our direct ancestors around 40,000 years ago. The real question is: how much were they like us?

Deceptive appearance

It's a debate that's been raging ever since Neanderthals were first identified in Germany's Neander Valley over 150 years ago. Their jutting brows, protruding noses and stocky, muscular frames were the start of their PR debacle, with the Victorians declaring them a primitive 'missing link'. "But just because Neanderthals looked primitive, it doesn't mean they were primitive," explained the late Dr Harold Dibble in an interview in 2014. Before his death in 2019, Dibble was an archaeologist and the professor of anthropology at the University of Pennsylvania.

Since then, researchers have scrutinised the remains of over 100 different individuals, scattered across time and geography, from Spain to Siberia. Far from savage, the fossil remains reveal that Neanderthals lived in small social groups, where they nursed their sick and cared for their disabled. One adult, found in a cave in Iraq's Zagros Mountains, apparently survived years after an injury to the

"Just because the Neanderthals looked primitive, it doesn't mean that they were primitive"

Professor Harold Dibble

IMAGE © Getty Images

Key questions about Neanderthals

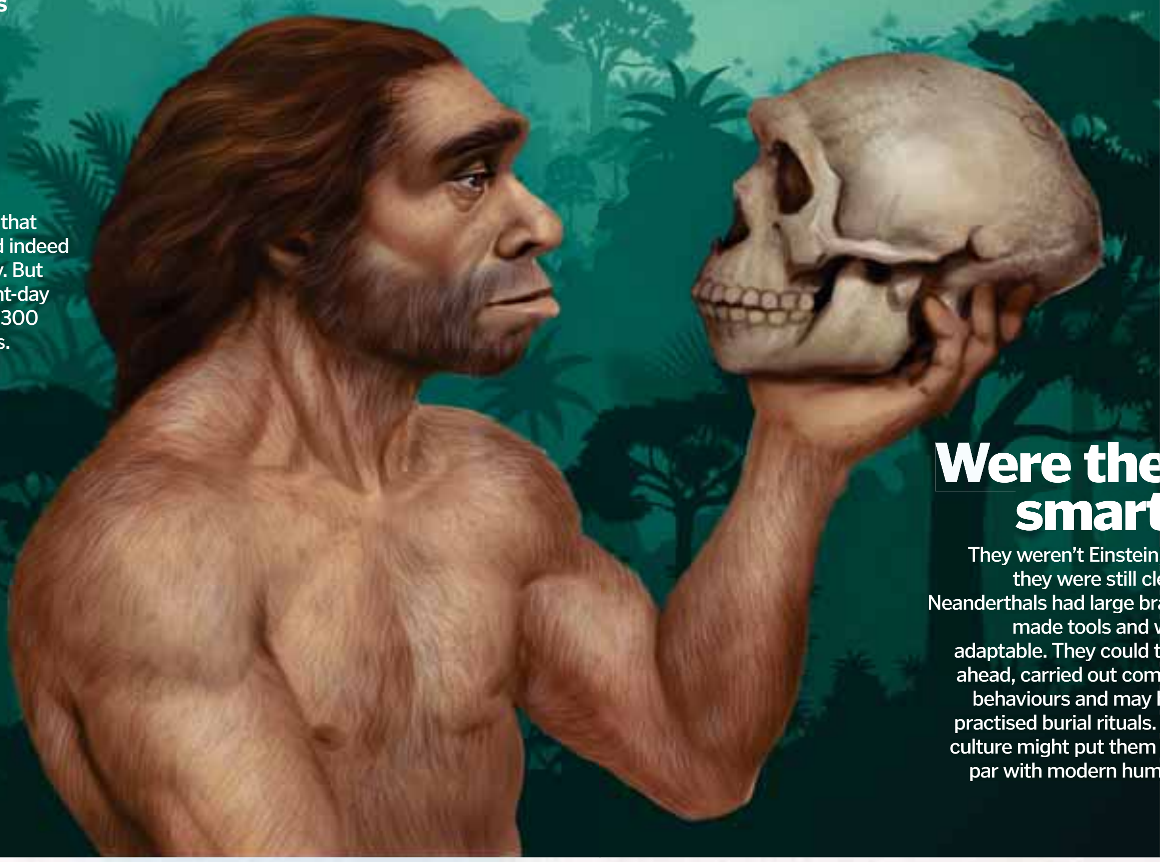
Separating fact from fiction has always proved difficult

Did we kill them off?

Neanderthals went extinct soon after modern humans arrived in Europe 40,000 years ago, prompting speculation that we caused their downfall. But their tiny population, small gene pool and battering from climate change are more likely to have spelled their doom.

Did we interbreed?

Recent DNA analyses have confirmed that modern humans and Neanderthals did indeed have sex, settling years of controversy. But the Neanderthal DNA lurking in present-day non-Africans is the result of as few as 300 sexual trysts between the two species.



Could they talk?

Neanderthals could definitely communicate, but whether or not they could 'talk' is still debated. Recent computer modelling of a Neanderthal's hyoid bone (a horseshoe-shaped structure in the neck) suggests that they were physically able to generate speech.

Were they smart?

They weren't Einstein, but they were still clever. Neanderthals had large brains, made tools and were adaptable. They could think ahead, carried out complex behaviours and may have practised burial rituals. This culture might put them on a par with modern humans.

Neanderthals could have hunted co-operatively to bring down large mammals

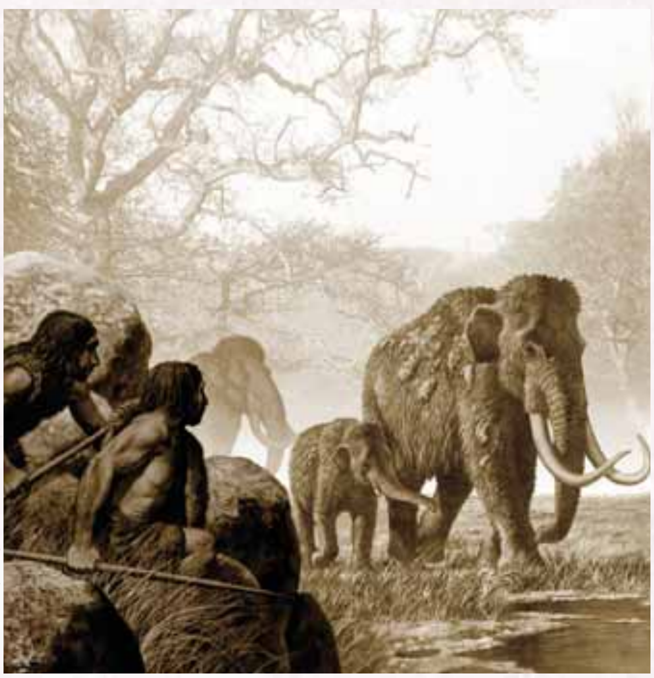


IMAGE © Getty Images

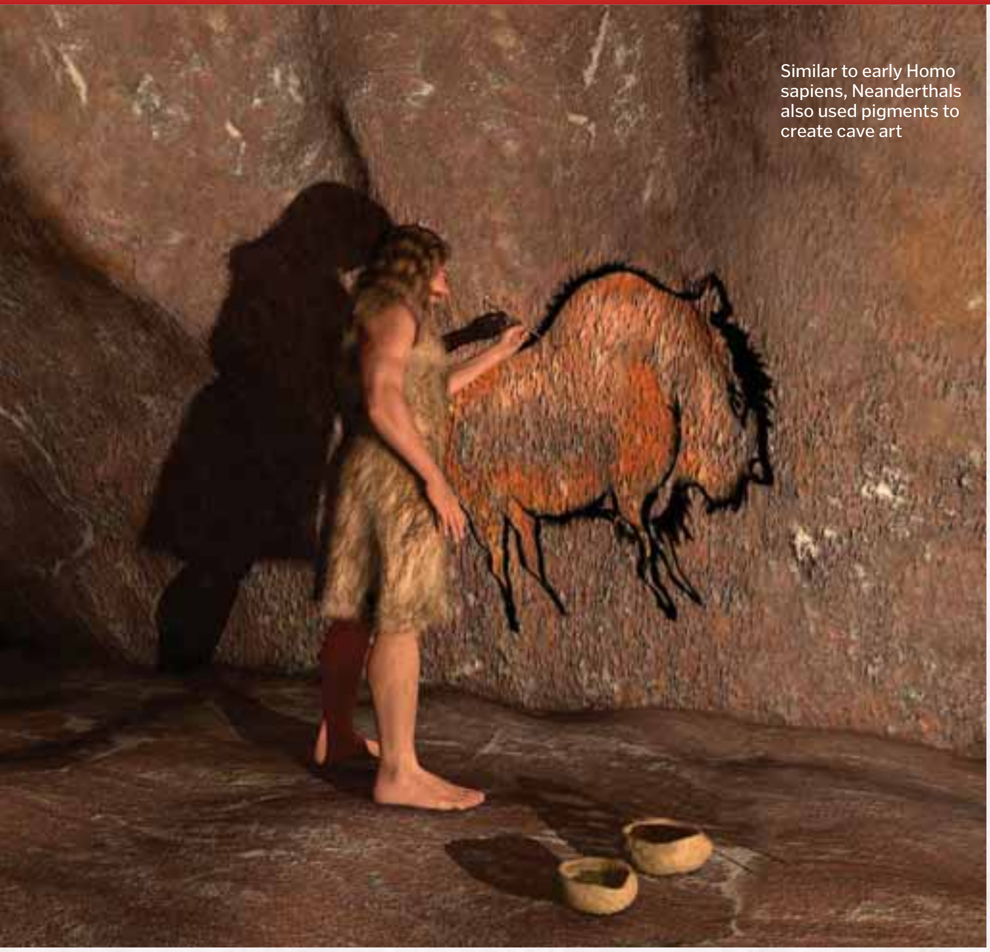
skull left him partially blind. He would have died quickly without the support of others around him. There is also evidence that the Neanderthals built shelters and hunted co-operatively.

Sophisticated behaviour

Some argue that Neanderthal technology was fairly complex. In 2013 researchers in the Dordogne, southwest France, unveiled Neanderthal lissoirs - polished tools hewn from deer ribs that were used to smooth hides and create softer, more water-resistant leather. Other sites in France and Spain have yielded distinctive curved flint knives, intentionally dulled on one side so they could be hand-held, and foot-long ivory spear points bearing tiny incisions to help them fit onto the handle. "Making these objects involved some very complex behaviour," says Dr Francesco d'Errico, principal investigator and professor at the Centre of Early Sapiens Behaviour.

But just because Neanderthals had some complicated kit, it doesn't mean they had culture. After all, many animals such as crows and otters use tools, but they don't visit art galleries. To infer culture, archaeologists look for evidence of symbolic thought. The ability to create symbols, they argue, underpins language, communication and modern human behaviour. In the last few years, researchers have unearthed various findings they say reflects this most human of traits. In 2010, d'Errico and colleagues described a haul of artefacts from two Neanderthal sites in southeast Spain. It included painted scallop shells that were probably worn as pendants, and spiny oyster shells containing pigment residues. It's thought the latter were used to make and store cosmetics. A bone with a pigment-tipped point, also found at one of the sites, could have been used to mix and apply the colour.

"We don't see these pigments being used by the Neanderthals to paint caves," says archaeologist Dr Alistair Pike at the University of Southampton, who was not involved with the work. "It's reasonable to



Similar to early Homo sapiens, Neanderthals also used pigments to create cave art

IMAGE © Thinkstock

assume they were decorating their bodies with them." These archaeological finds date from 50,000 years ago – around 10 millennia before modern humans arrived in Europe from Africa. "It's evidence that Neanderthals were capable of symbolic thought," says Pike.

Burial evidence

But there's a more touching indication of human culture. Neanderthal remains are found across Europe and at some sites, they are placed so carefully in the ground that some think the burials are deliberate. In 2013, researchers completed a re-excavation of a Neanderthal burial site in France, revealing additional bodies and animal bones. Scientists working on the site said that the Neanderthal bones must have been quickly covered because they weren't weathered. "The discovery not only confirms the existence of Neanderthal burials in western Europe, but also reveals a relatively sophisticated cognitive capacity to produce them," says study author Dr William Rendu, a paleontologist from New York's Center for International Research in the Humanities and Social Sciences. For some, the growing evidence of symbolism and behavioural complexity is sufficient to put Neanderthals on a par with modern humans. "The gulf between us and Neanderthals has narrowed recently. Neanderthals are seen as having at least some degree of equality with humans," says anthropologist Professor Chris Stringer, at the Natural History Museum in London. But for others, the evidence remains equivocal, and proof of culture is still lacking. "We can't say for sure exactly who made these tools and ornaments," said Dibble. Artefact dating techniques are imprecise and the different layers of archaeological sites can get mixed up. And if they were Neanderthal, what's to say they didn't trade with or copy the technology from modern humans? "I think Neanderthals were intelligent," said Dibble. "But I don't think they had modern human culture."

One thing is for sure: Neanderthals were able to survive for thousands of difficult years without wrecking their planet, making them clever, adaptable and resilient. We modern humans may like to think of ourselves as intelligent, but in the time we've been around, we've made quite a mess. Perhaps it's high time the term 'Neanderthal' stopped being used in the pejorative and started to be seen as a compliment.

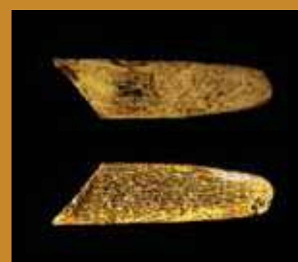
Four interesting examples of neanderthal technology

A number of researchers credit Neanderthals with technology that, for its time, was pretty sophisticated

Glue

Neanderthals heated and treated birch bark to produce a sticky, resin-like glue, which they probably used to help attach stone knives to wooden hilts. The adhesive would have needed to have been smouldered for several hours at a tightly controlled temperature, implying a sophisticated mastery of fire.

Tools



Neanderthals certainly worked stone and made hand axes, but they may also have produced more specialised tools including distinctive curved flint knives and lissoirs. The latter was a tool fashioned from deer ribs and was used to smooth animal hides, giving a shinier, water-resistant finish.

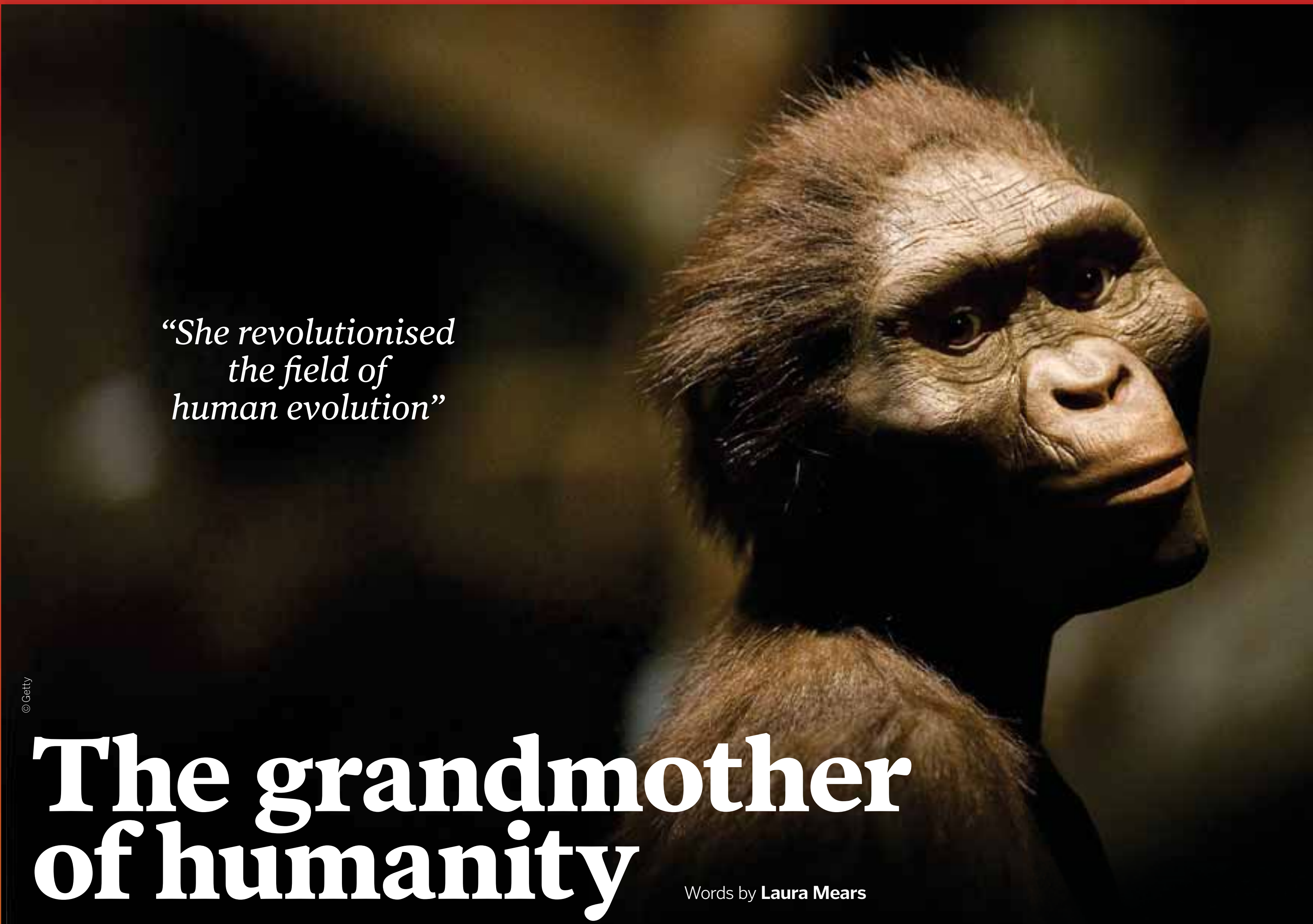
Cosmetics

The recent discovery of fancy shells containing colourful pigment residues has fuelled speculation that some Neanderthals made and stored make-up, and decorated their bodies with it. But pigments also had other probable uses, such to help tan animal hides.

Jewellery

Evidence that Neanderthals liked a bit of bling is mounting, with multiple finds of ornaments made from teeth, bone and shell. Analysis of skilfully butchered wing bones suggests feathers were purposefully removed, which may have been used for personal decoration.

IMAGE © The Trustees of the Natural History Museum, London, J. Zilhão, University of Barcelona/ICRE, Rama



© Getty

“She revolutionised the field of human evolution”

The grandmother of humanity

Words by **Laura Mears**

Meet Lucy, the 3-million-year-old ape that walked on two legs

When scientists found Lucy in the 1970s, she revolutionised the field of human evolution. At the time, she was the oldest and best-preserved example of a human-like species ever discovered. An incredible 40 per cent of her skeleton had survived in Ethiopia’s Afar Depression, and the tales it had to tell were astonishing.

Lucy was a member of a species called Australopithecus afarensis, and she lived more than 3 million years ago. Wear on her wisdom teeth shows that she was fully mature when she died, but she would have grown up quickly. She was probably only around 12 years old and weighed just 29 kilograms (64 pounds), barely half as much as a human female. Her brain was only one-third of the size of ours, and her face was ape-like, with a powerful jaw. She had curved fingers, and marks on her upper arm bone show that her muscles were strong, both signs that she was a competent climber.

However, unlike the apes we see today, Lucy walked on two legs. Her lumbar vertebrae, the bones in the small of her back, curve inwards like ours. Her pelvis is wide, and she has ‘valgus knees’, meaning that her legs bend inwards slightly, which have helped her balance by bringing her feet underneath her body.

The discovery of Lucy’s skeleton changed the way we think about human evolution. Two features set modern humans apart from other apes: our large brains and our ability to walk on two legs. Which of these adaptations came first had been a mystery – Lucy provided us with the answer.

Finding Lucy

Hadar in Ethiopia is part of the Afar Triangle, a volcanic region at the junction of three tectonic plates. It was home to ancient humans, and eroding rocks occasionally reveal their remains.

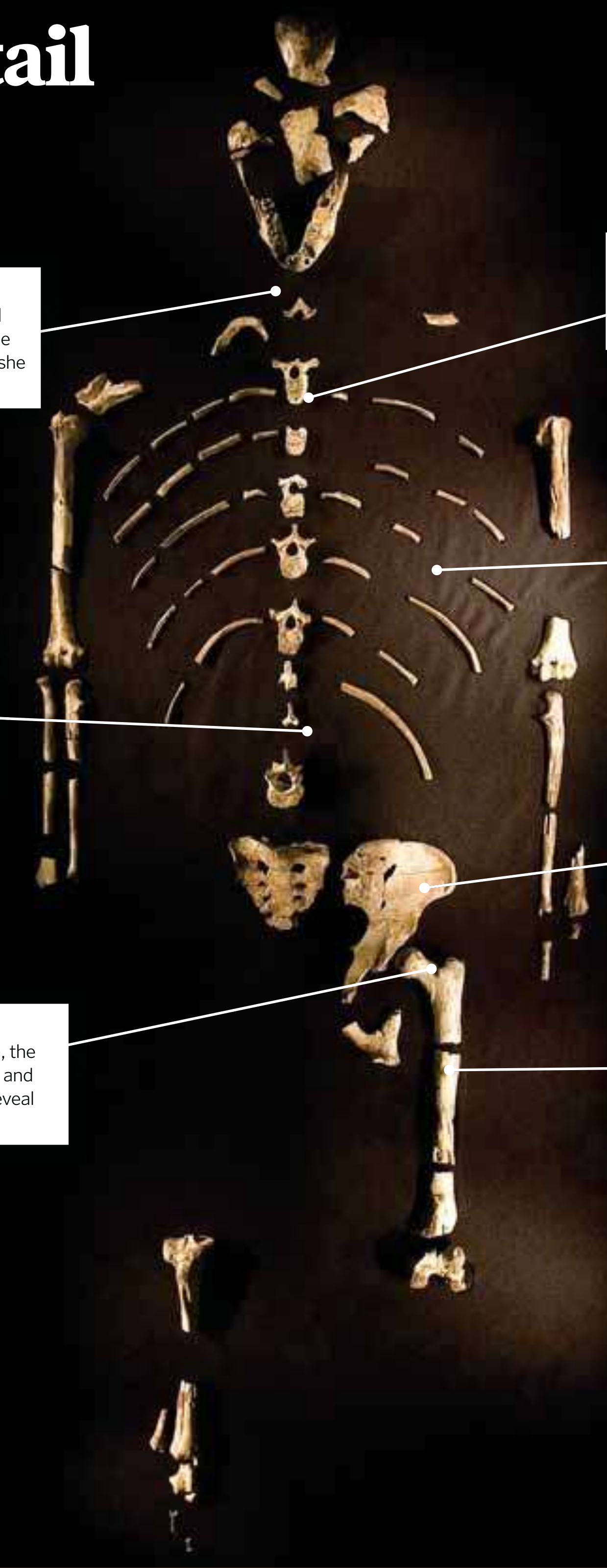
On 2 November 1974, Dr Donald Johanson, a paleoanthropologist, was there with his student, Tom Gray. The pair had been out exploring and had decided to walk back to their car via a ravine. As they walked, they noticed an elbow bone sticking out from the sediment. Nearby, they found fragments of a skull, ribs, a thigh bone, a pelvis and a jaw. It took weeks of careful work to recover all the pieces, but by the time the excavation was complete they had found almost half of a skeleton.

On the night of this incredible discovery, Johanson and the team listened to The Beatles’ *Lucy in the Sky with Diamonds* on their tape deck. Inspiration struck, and that’s how this famous fossil got her name.

© Alamy

Lucy in detail

Lucy's remains reveal hidden clues about how she lived and died



Adult teeth
Lucy's wisdom teeth had come through by the time she died, indicating that she had reached adulthood.

3.18 million years old
Scientists managed to work out Lucy's age by looking at the rocks that surrounded her remains.

One person
If Lucy's remains belonged to more than one individual, you might expect duplicate bones, but every fragment was unique.

Plant-based diet
Lucy's cone-shaped rib cage suggests she had a big stomach, an indicator that she ate a tough plant-based diet.

Bitten by a predator
Lucy's cause of death is unknown, but she has a puncture mark from a carnivore tooth on her pelvis.

Walked upright
The angle of Lucy's thigh, the lip of bone near her knee and the shape of her pelvis reveal that she walked upright.

Female
The length of Lucy's thigh bone puts her height at just over one metre (3.3 feet), revealing that she was probably female.

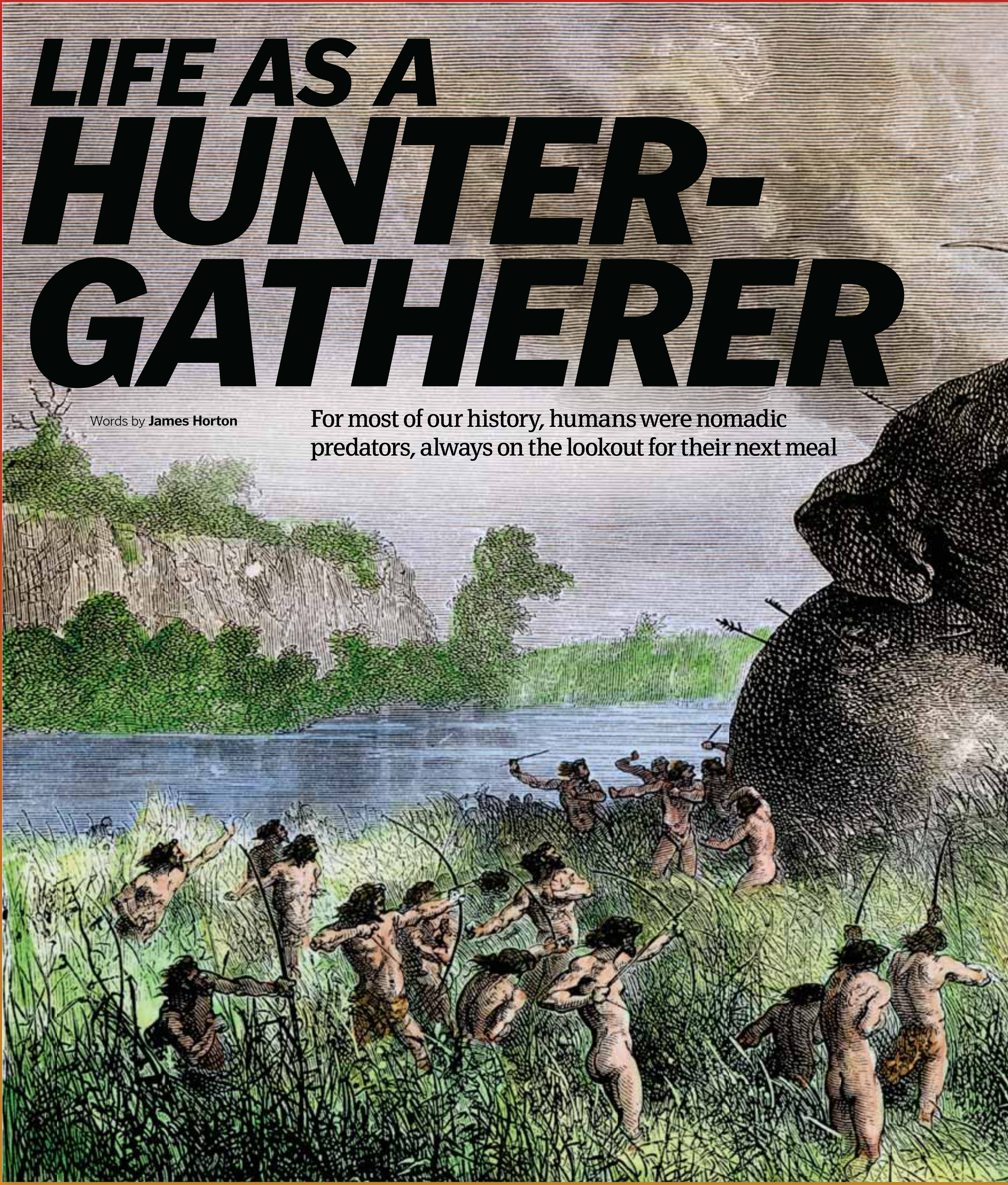
How did Lucy die?

The cause of Lucy's death is hotly contested, but anthropologist John Kappelman and his colleagues think that she might have fallen from a tree. There are cracks in her bones that match the types of fractures we see when primates put their arms out to break a fall, and according to Kappelman's reconstruction, Lucy fell from a height of 15 metres (50 feet) and hit the ground feet first. She broke both her ankles and knees before tumbling forward onto outstretched arms, damaging her pelvis, wrists, ribs and skull in the process.

The trouble with this theory is that it's hard to prove. According to other researchers, the damage to her bones could also have occurred after she died.

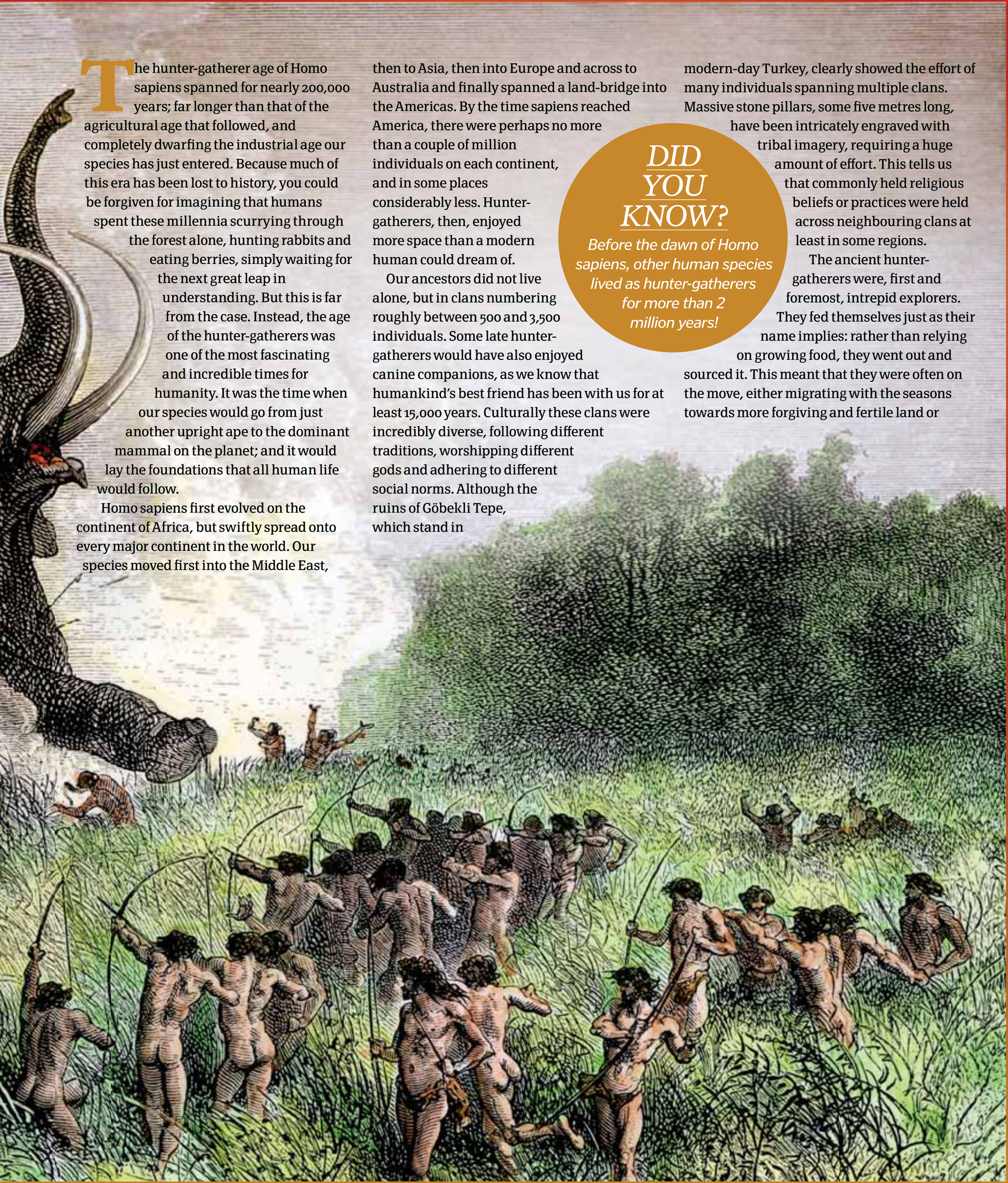
A reconstruction of Lucy's skeleton at the Cleveland Museum of Natural History

LIFE AS A HUNTER-GATHERER



Words by **James Horton**

For most of our history, humans were nomadic predators, always on the lookout for their next meal



The hunter-gatherer age of Homo sapiens spanned for nearly 200,000 years; far longer than that of the agricultural age that followed, and completely dwarfing the industrial age our species has just entered. Because much of this era has been lost to history, you could be forgiven for imagining that humans spent these millennia scurrying through the forest alone, hunting rabbits and eating berries, simply waiting for the next great leap in understanding. But this is far from the case. Instead, the age of the hunter-gatherers was one of the most fascinating and incredible times for humanity. It was the time when our species would go from just another upright ape to the dominant mammal on the planet; and it would lay the foundations that all human life would follow.

Homo sapiens first evolved on the continent of Africa, but swiftly spread onto every major continent in the world. Our species moved first into the Middle East, then to Asia, then into Europe and across to Australia and finally spanned a land-bridge into the Americas. By the time sapiens reached America, there were perhaps no more than a couple of million individuals on each continent, and in some places considerably less. Hunter-gatherers, then, enjoyed more space than a modern human could dream of.

Our ancestors did not live alone, but in clans numbering roughly between 500 and 3,500 individuals. Some late hunter-gatherers would have also enjoyed canine companions, as we know that humankind's best friend has been with us for at least 15,000 years. Culturally these clans were incredibly diverse, following different traditions, worshipping different gods and adhering to different social norms. Although the ruins of Göbekli Tepe, which stand in modern-day Turkey, clearly showed the effort of many individuals spanning multiple clans. Massive stone pillars, some five metres long, have been intricately engraved with tribal imagery, requiring a huge amount of effort. This tells us that commonly held religious beliefs or practices were held across neighbouring clans at least in some regions.

The ancient hunter-gatherers were, first and foremost, intrepid explorers. They fed themselves just as their name implies: rather than relying on growing food, they went out and sourced it. This meant that they were often on the move, either migrating with the seasons towards more forgiving and fertile land or

DID YOU KNOW?

Before the dawn of Homo sapiens, other human species lived as hunter-gatherers for more than 2 million years!

Today's hunter-gatherer societies

The agricultural age began slowly, in fits and starts across the globe, but eventually proved to be a boon. The hunter-gatherer societies simply could not keep up, and most were enveloped by the relentless tide of farming and land-swallowing that resulted from larger societies. But today there remains small pockets of people in Africa, Asia, South America and the Arctic who still adhere to the ancient hunter-gatherer lifestyle.

Some of these tribes have managed to carve out territory and remain in isolation. Most notably of these is the Sentinelese of the Bay of Bengal, who have inhabited the Andaman Islands for millennia. Although other tribes on the islands have contacted the outside world, the Sentinelese are notoriously protective of maintaining their way of life. They have been known to kill fishermen who stray too close, and launch arrows at boats and helicopters that dare to venture near.

Other tribes, such as the Hadza in Tanzania, have been more welcoming to intrigued visitors, but are at risk of being squeezed from their territory. Now forced to live in the bush, the Hadza are skilled hunters of baboon, wildebeest, zebra and buffalo. However, they are also forced to endure the punishing heat, malaria-carrying mosquitos and lack of drinking water, made worse by encroaching cattle farmers.

Despite these challenges, they have been noted to have a relaxed and joyful way of life, which makes you wonder how happy our ancestors might have been in even more forgiving circumstances.

Roughly a quarter of the Hadza tribe remain devoted to the hunter-gatherer lifestyle

migrating to new territory once the local foliage had been picked clean of sustenance.

While on their travels, they would survey every cave, roam every forest, inspect every potentially edible foodstuff. They would travel light, free from encumbering material possessions barring the essentials, and spend the nights when they weren't sleeping in caves or under shelters staring up at picturesque starry skies. Away from the campfire, the heavens would simply sparkle into life above their heads.

When dawn arrived, some would have stepped foot in an area that a human had never before seen, touched or smelled. They would see new creatures of all different shapes and sizes: funny amphibians who bounced from place to place; slimy gastropods who wore intricate shells on their backs; giant woolly carnivores who could tear them limb from limb. The sense of discovery nurtured by our millennia as hunter-gatherers still tingles within us today. But for a modern human to discover a novel environment, they have to travel to the bottom of the ocean, whereas the hunter-gatherers just needed to take but a few steps in the right direction.

The average life expectancy for hunter-gatherers was approximately 35 years old, but this was heavily biased by high rates of child mortality. If a hunter-gatherer were to survive into adulthood, they stood a good chance of surviving into their sixties. They were all incredibly fit, and exercised daily through foraging, hunting, roaming, weaving, playing and dancing. Plus, their diets included a wide array of food-types, ensuring a mixture of all essential and desirable nutrients. This enabled them to be better nourished than many of the peasant farmers who followed them.

The risks of epidemics were also reduced to essentially nil. After all, epidemics are often the result of dense populations and can be transmitted through bodily waste. The hunter-gatherers travelled in small, sparse bands, rarely remaining in one place for too long. If someone were to fall ill with an infectious disease, it would be unlikely to spread throughout the group.

Not all hunter-gatherers were nomads, however. Prior to the agricultural revolution, they may not have had the means to replenish local food supplies, but if food was naturally replenished swiftly or brought to them – such as via a body of water – then some took the opportunity to settle. The locals in these fishing villages would hunt with net, hook, spear and hands. Larger fish could be trapped or speared, and small molluscs could be scraped or pulled from rocks near the shoreline, providing nutrients for the villagers all year round.

Once settled semi-permanently, the hunter-gatherers could sew clothes, weave bags and mould pottery. They would forage and hunt for an average of perhaps 35 hours per week, giving them ample time to decorate their pottery, make bracelets and necklaces from animal bone, carve inventive sculptures, and paint impressive murals. They would achieve such beautiful works of art using dyes and pigments either collected on their travels or traded for with other nomadic clans, enabling them to

The nearly 10,000-year-old paintings in the Cueva de las Manos ('Cave of Hands') in Argentina shows the artistic flair of hunter-gatherer societies

DID YOU KNOW?

Marine shells were popular items in land-locked clans, who would trade for them with coastal tribes

The hunter-gatherer menu

Unearth the wide-ranging foods that kept our ancestors fuelled on their travels

Nuts and seeds

Long-lasting and bountiful, raw nuts and seeds were packed full of important fibre but were also cooked to unlock more of their nutrition.

Molluscs and fish

Migrating fish could be speared seasonally, but shellfish, oysters and mussels could be cooked all year round and their shells used as decorative ornaments.

Eggs

Hunter-gatherers would steal eggs by climbing trees and raiding nests. The eggs could swiftly be eaten raw and were packed full of protein and fats.

Berries and fruits

A seasonal treat worth migrating for, berries and fruits were one of the rare sources of sugar-rich food types that were available to hunter gatherers.

Roots

Carrots, onions, yams, water chestnuts, beetroot and other vegetables provided not only a key source of minerals, vitamins and carbohydrates but also added unique flavours.

Honey

Still much sought after by surviving hunter-gatherer societies, beehives could be found by following honeyguide birds, and granted a long-lasting, sweet and nutritious treat.

Meat

Meat is packed full of proteins and fats, and could be smoked, dried or frozen to offset rotting. Furs, pelts and bone came as an added bonus from hunting.

Bone marrow

Before humans were able hunters, we would wait until the lions and jackals had eaten their fill before swooping in to ingest the bone marrow of fallen prey.

Nettles and leaves

Garlic mustard and herbs added extra spices and flavour to a hunter-gatherer dish, and nettles may have been used for both medicine and weaving material.

Hunters used sharp weapons, fire and sophisticated tactics to bring down large and powerful prey

leave their fingerprints behind – sometimes literally – after they'd moved on.

However, the life of a hunter-gatherer was certainly not without peril. Insight from modern hunter-gatherer societies and recovered skeletons suggests that it might have been a sometimes harsh and unforgiving life. Modern hunter-gatherers have been known to bury unwanted babies alive, abandon their sick and murder their old. This may seem inhumane, but there was very little room for those who could not provide in truly nomadic clans. Their lifestyles may have been particularly violent in other ways, as well. Hunter-gatherer skeletons recovered from the Americas had a particularly high frequency of skeletal trauma likely caused by weapons. Whether this was clan warfare or internal rivalry is difficult to say, but it appears that certain clans were swift to settle their grievances with violence.

But perhaps the greatest cruelty committed throughout the hunter-gatherer era wasn't what humans did to each other, but the ecological devastation we unleashed on the world following our arrival. The majority of a hunter-gatherer's calories came from foraging. Berries, nuts, seeds, roots and fruits were relatively easy to come by and required little effort to consume. But hunting often represented a more tantalising prize. A big mammal may be dangerous and difficult to take down, but they would provide sometimes tons of meat, coveted pelts and furs, bone and sometimes ivory. They were a prize worth fighting for.

Unfortunately, the adaptability, ingenuity and instinctive curiosity of Homo sapiens meant that they could arrive as an apex predator and eradicate a species before it had a chance to adapt to their presence. This happened when we first arrived in Australia; likely some particularly creative-types built sea faring vessels and traversed the sea to the isolated island, and there they encountered an alien world full of gigantic beasts. This megafauna numbered at 24 species when the humans arrived. A mere few thousand years later, however, only one remained. The kangaroo was lucky, or perhaps too difficult to hunt. But it's easy to imagine a world where we raise our eyebrows in amusement after reading of a two-metre-tall hopping marsupial, which like its contemporaries was wiped out by the storm of invading hunter-gatherers. Many other animals, from many other continents, were driven to extinction by our ancestors. These included the giant sloth of the America's (which weighed up to eight tons!), and the elephant bird of Madagascar, which was about twice the size of an ostrich. The hunter-gatherers were so successful at slaughter thanks to their big brains. In fact, some scholars believe that they had larger brains than we do today. After all, it's

Hobbies of the hunter-gatherer

It wasn't all work and no play for our ancestors

Gossip

Humans have always loved idle chit-chat and rumour mongering. And gossip was likely essential for maintaining a cohesive social structure involving many individuals.

Arts and crafts

Decorated pottery, garments, hand-carved miniature carvings, paintings and intricately engraved weapons were formed ubiquitously in hunter-gatherer societies, helping to express the individuality of the clan.

Music

Musical instruments have existed for at least 40,000 years, but are likely much older. Hunter-gatherers would practise the flute for use during times of celebration.

Storytelling

With no written word, there was no better way to pass down knowledge and a sense of morality, and invoke wonder than by telling a good story.

Party

During rituals, members of the clan would sing and dance to a background of music, sometimes endowed with paint and other forms of decoration.

easier to survive in the modern world of abundance brought about by the agricultural and industrial ages than it was in their time. A hunter-gatherer who lacked intelligence, dexterity and fitness could not hope to thrive in their clan, and so their genes would soon dwindle from existence.

In addition to their arsenal of clubs, hatchets, spears and arrows, hunter-gatherers employed ingenious tactics to subdue large and dangerous prey. We know that at least one ancient clan corralled fleeing bison so that they would charge off a 15-metre precipice. The humans would stab or club to death any of those who had been wounded but not outright killed from the fall. The clan could then harvest piles of meat, and smoke, dry or – if the climate was agreeable – freeze the meat to preserve it.

The most dangerous weapon in the human arsenal, however, was fire. Fire had been a breakthrough in humanity's story; overnight we became equipped to guard ourselves from predators in the dark, warm ourselves in the cold, and turn inedible items of food into nutritious feasts. But fire was also used for intentional devastation of woodlands. Hunter-gatherers could create desirable pasture land for game by torching thick foliage to the ground.

DID YOU KNOW?

Evidence suggests that Homo sapiens occasionally mated with other Homo species who shared their territory

Bones were excellent material for fashioning into needles

It was likely a combination of our actively hunting and purposefully ruining the natural habitats of megafauna that drove those species extinct. Although they weren't consciously aware of it, hunter-gatherers were the architects of ecological mass-genocide unrivalled by any species that came before them.

The age of the hunter-gatherer was a time of huge change for humanity. Our species had stepped out from Africa and fast colonised every continent on the planet, making large ecological changes wherever we went. In hunter-gatherer tribes, humanity began to develop rich cultures and traditions that would shape society moving forward into the agricultural age.

They had learned of the potential prosperity but also perils offered by exploration, and had garnered intimate knowledge of the natural world. And in doing so, they had set the stage for humanity's next step.

CULTURE & SOCIETY

Stone Age towns

Discover why and when our ancestors put down their roots to establish permanent settlements

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The agricultural revolution

How the switch from hunting to farming changed the course of human history

© Pixabay

Prehistoric painting

The ancient artworks that provide a rare insight into the lives of Palaeolithic people

The cradle of civilisation

Find out how society as we know it began in the ancient region of Mesopotamia

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50 greatest inventions

From the wheel to the 3D printer, explore some of humanity's most important innovations

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Çatalhöyük settlement on the Konya Plain in Turkey

Ancient urban living

9,000 years ago this settlement in Çatalhöyük, Turkey, was a tightly packed community

2x © Getty

The first human settlements

Words by **Jodie Tyley**

More than 10,000 years ago, nomadic tribes put down their roots to establish the very first towns

Rooftop entrance
Houses were built back to back, so the rooftops became like streets. People climbed into their homes using ladders.

Building materials
Houses were made from mud that hardened in the sun. Walls measured 50 centimetres thick and stood over two metres tall.

Early humans led a nomadic life, constantly travelling in search of food and water. Small tribes would create basic shelters in caves or other rock formations, and then leave to follow the seasonal changes and migration of the animals on which they depended. This way of life continued for hundreds of thousands of years, until the first farms marked the dawn of a new era – the Neolithic period (or New Stone Age), around 12,000 years ago. By discovering that crops could be grown and animals could be tamed, the hunter-gatherers began to settle down and build permanent dwellings.

Neolithic towns were constructed from any natural materials that could be found nearby, but most houses were made using the wattle and daub technique. The wattle was made by weaving branches between wooden frames, and the daub – a mixture of manure, mud, hay and water – was smeared over the top, helping to strengthen the structure and keep the inhabitants warm and dry. However, when wood was not available, as on Scotland's Orkney Islands, Neolithic people used stone to build their houses, and even used it for their furniture.

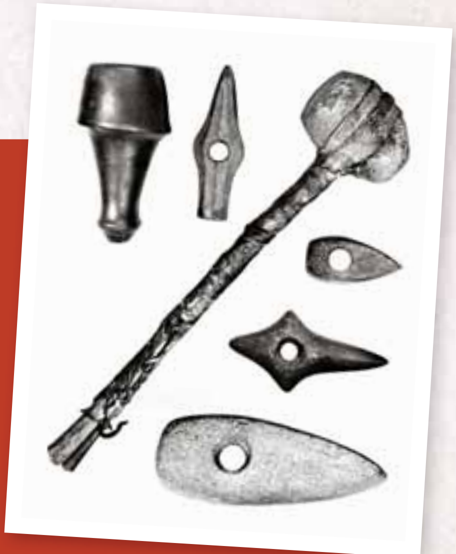
In the settlement of Çatalhöyük in Turkey, the residents used mud bricks that hardened in the hot sun. This is one of the largest settlements to have been discovered, and is thought to have housed as many as 8,000 people. The site was built near marshy swamps – a valuable source of water and building materials. However, archaeologists think it wasn't just resources that drew such large numbers of people together, but also security against enemies, division of labour and community rituals.

Life was still pretty primitive for Neolithic settlers, but they thrived in these early urban environments and would pave the way for civilisation as we know it.

Tools of the trade

The Stone Age was a period when early humans used tools and weapons made of stone, beginning around 3.4 million years ago. Flint and obsidian (volcanic glass) were shaped and sharpened using a hammerstone, creating arrow heads, knives and hand axes, and were stuck onto pieces of wood using pine resin, beeswax and charcoal. These were used for hunting and preparing food.

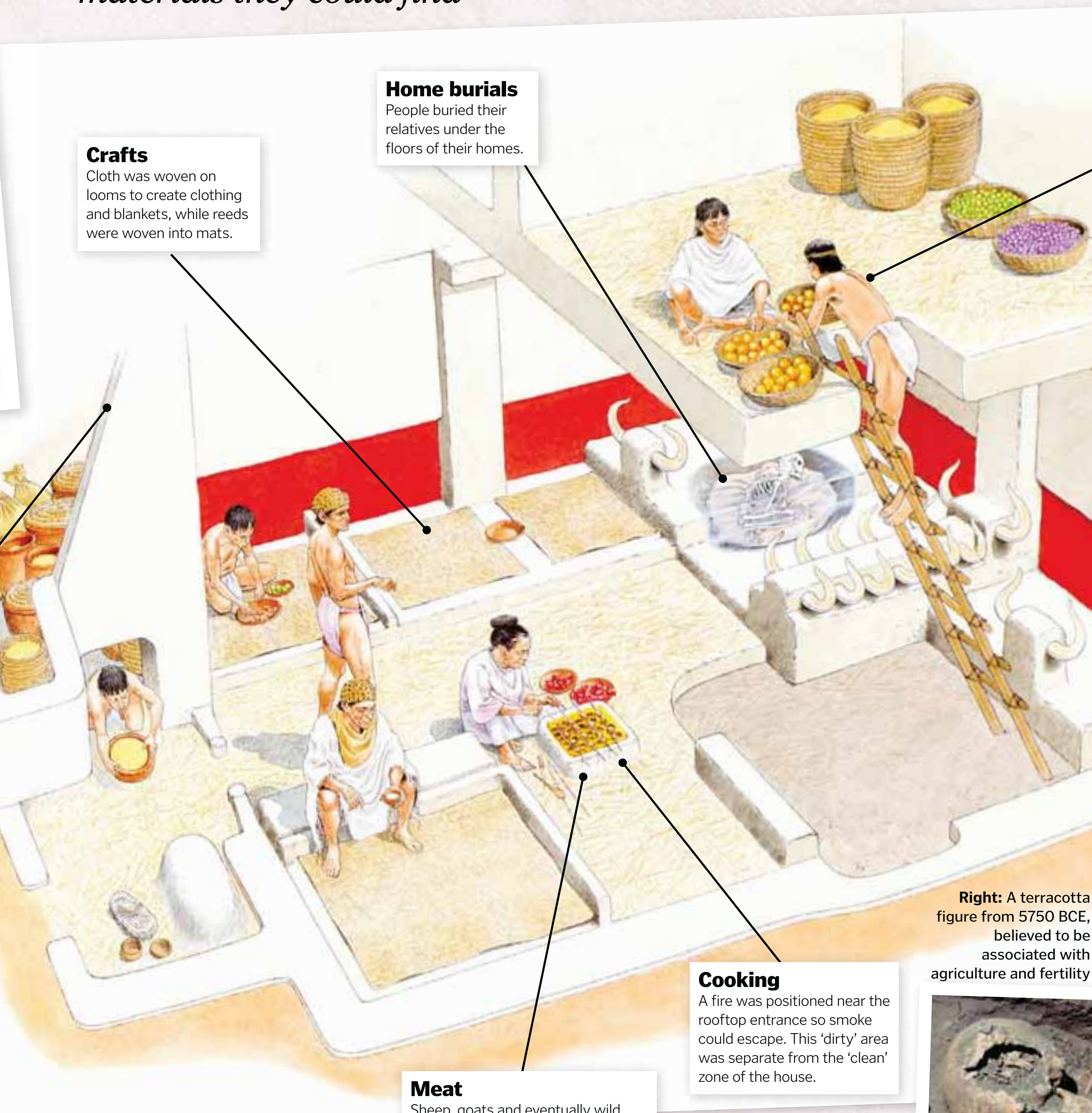
The simple but effective Neolithic toolkit wasn't exclusively made of stone, however. Bones and antlers were used to create things like needles, combs and even instruments. The Stone Age came to an end when humans first started using metal around 5,000 years ago.



Stone Age tools were made from flint, obsidian, antlers and bones

© Alamy

"Neolithic towns were constructed from any natural materials they could find"



Right: A terracotta figure from 5750 BCE, believed to be associated with agriculture and fertility

Right: Skeletal remains found in Çatalhöyük

Neighbours from hell

Çatalhöyük may be a model of early urban living, but its residents were far from model citizens. A recent study suggests that when the population was at its largest, overcrowding led to violence. Excavated skulls show signs of healed fractures, and others had been hit with round, hard objects. Many of the victims were women. Clay balls unearthed at the site seem to fit the size of the weapon and may have been used as projectiles flung by a slingshot.

People and animals living in such close quarters could have increased the spread of disease, adding to stress in the community.

Professor Clark Spencer Larsen, who led the study, said, "Çatalhöyuk was one of the first proto-urban communities in the world, and the residents experienced what happens when you put many people together in a small area for an extended time. It set the stage for where we are today."

The agricultural revolution

From foragers to farmers, discover how the seeds of modern civilisation were sown

Words by **Jodie Tyley**

Some 11,000 years ago, the way humans lived changed forever when hunter-gatherers became farmers. It brought an end to the nomadic lifestyle – constantly moving with animal migrations and the changing seasons. Humans started to build permanent dwellings instead, and communities grew among the crops they learned to cultivate.

This was such a seismic shift in society that it is known as the Neolithic Revolution – from the Greek words for 'new' (neo) and 'stone' (lithic). It's thought that the first farms originated in the Fertile Crescent, or 'Cradle of Civilization' around 9000 BCE – a region that spans modern-day southern Iraq, Syria, Lebanon, Jordan, Israel and northern Egypt – where regular rainfall and fertile soil made it an ideal environment for growing crops and raising livestock. This area was also the birthplace of writing, the wheel, currency, astronomy and many more innovations that changed the world.

Studies have revealed that we don't have one early population to thank for the Neolithic Revolution, however, but several groups of people across the region. Scientists tested the DNA of the world's first farmers and found that they were genetically distinct, so it's likely that the practice was independently invented multiple times and techniques would have developed gradually. Over millennia, the migration of farmers slowly introduced agricultural methods and tools throughout western and southern Asia, northern Africa and Europe.

But what caused people to stop foraging and settle down? There are many possible theories. Some suggest that increased competition for food might have sparked the need for alternative sources. Others think that it might have been driven by climate changes at the end of the last Ice Age around 14,000 years ago. Or perhaps the human brain reached a new level of intelligence that triggered this lifestyle change. It's

Farmyard trivia

Five fascinating facts about the first farmers and their agricultural methods

Strong as an ox

Around 4000 BCE, farmers in northern Iraq began castrating bulls, turning them into oxen, which were much easier to control when pulling the plough.

Extreme agriculture

Settlers on the remote Scottish Orkney Islands circa 3500 BCE stood a slim chance of survival if it weren't for their seaweed-eating sheep. Studies show they started guzzling the green stuff from the moment of their arrival.

Bite of a difference

The reason why we can make labiodental sounds like 'f' and 'v' is down to the Neolithic Revolution. There's evidence to suggest that dietary changes had an effect on our mouths and teeth.

Migration of ideas

Analysis of ancient DNA has revealed that it wasn't just the idea of farming that spread to Europe, but the farmers themselves. Experts think they mixed with local hunter-gatherers rather than wiping them out.

Farmer's best friend

Dog DNA in archaeological sites around Europe can be traced to a common ancestor that originated in the Near East, suggesting that farmers travelled with their beloved canines (as well as their livestock, cultivated plants and tools).

DID YOU KNOW?

In ancient Egypt, grain was used as currency – the builders of the pyramids at Giza were paid in bread and beer

The first farmlands

Find out where some of the first crops and animals were domesticated

DID YOU KNOW?

Europe's first farmers used livestock manure as fertiliser on their crops 8,000 years ago

Wheat was one of the first crops to be domesticated, and to this day it remains the most widely grown crop in the world

"It's thought that the first farms originated in the Fertile Crescent around 9000 BCE"

Farming originated in a crescent-shaped region in the Middle East

A saddle quern found at Jarlshof (Shetland, Scotland) archaeological site showing 2500 BC prehistoric and Norse settlements

likely that the reasons varied depending on the region.

By taking control of food production, populations grew fast and the division of labour freed up time for leisure activities such as art, pottery and other crafts. However, more mouths to feed meant when food shortages, livestock disease, pests or drought struck, famine followed. A study has revealed that the spread of agriculture through central Europe 7,500 years ago coincided with a pattern of boom-and-bust in the size of regional populations.

That wasn't the only drawback, either – skeletal and dental analysis has shown that farming communities had poorer nutrition and shorter life expectancies than foragers due to eating a limited variety of foods. Scientists also found that, over time, farmers evolved to have weaker bones that were more susceptible to breaking, while hunter-gatherers had bones as strong as a modern orangutan! This is likely due to the more sedentary lifestyle – working and living in a defined area rather than roaming the landscape in search of food.

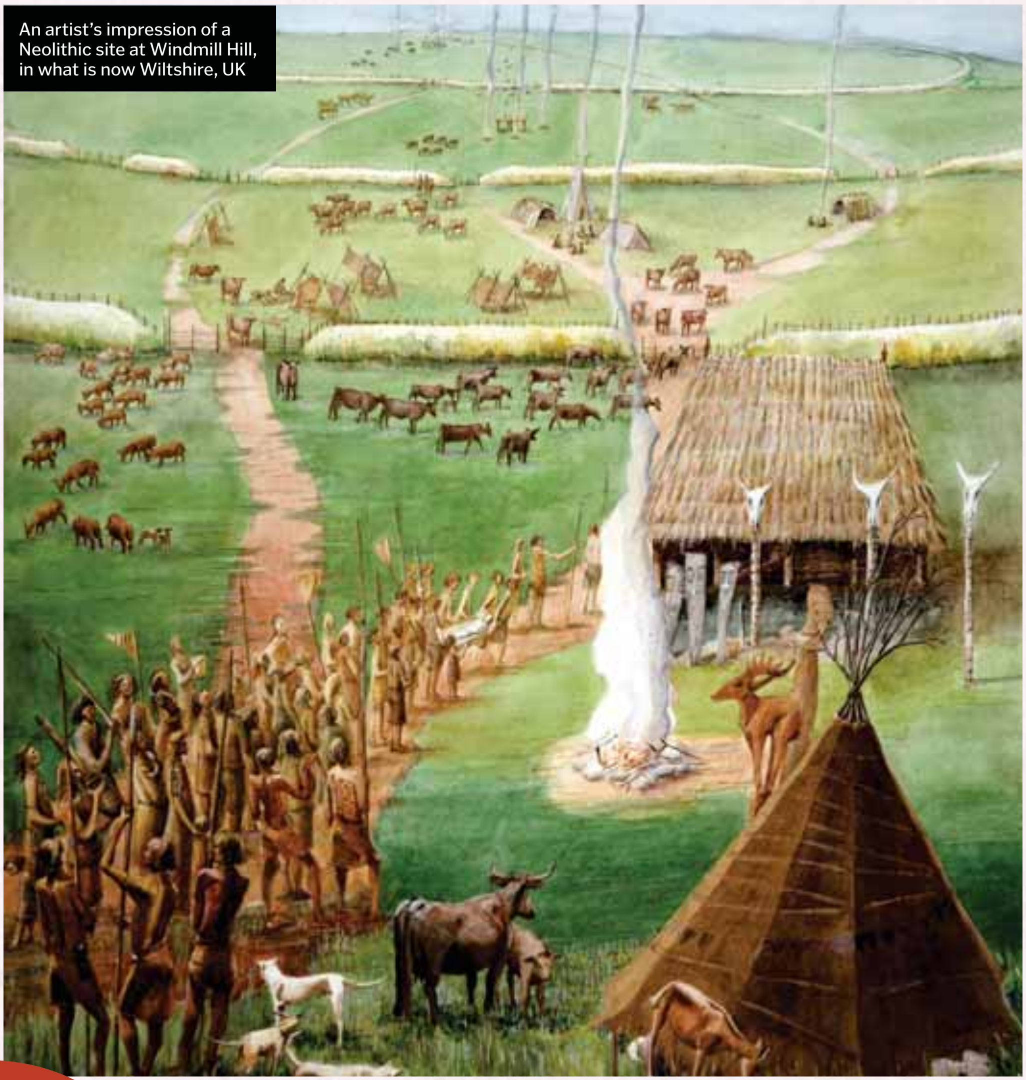
Another drawback to farming was the outbreak of disease caused by people living in close proximity to each other and their livestock. These densely populated areas means that bacteria could thrive and mutate into new and deadly forms rather than running its course. Nevertheless, animals were integral to the community – providing labour, additional meat and milk for nutrition, and skin and wool for clothing.

The first domesticated animals were bred from the creatures that Neolithic man once hunted – pigs came from wild boars, and goats from the Persian ibex, for instance, while dogs helped to herd and protect them (having been domesticated long before agriculture developed). Later, cattle became a farmyard staple, as they played a symbolic role in rituals and art in the Near East, leading some to think they were first herded for sacrifices and feasts. They came to realise their full potential when, following the invention of the wheel in 4000 BCE, farmers began attaching oxen to ploughs to churn the soil and prepare it for seeding – a much more effective method than the sticks early farmers had used. The manure they produced also served as a fertiliser.

"Pigs came from wild boars, and goats from the Persian ibex"

DID YOU KNOW?

Some modern-day Europeans can trace their DNA to early farmers living in the Aegean

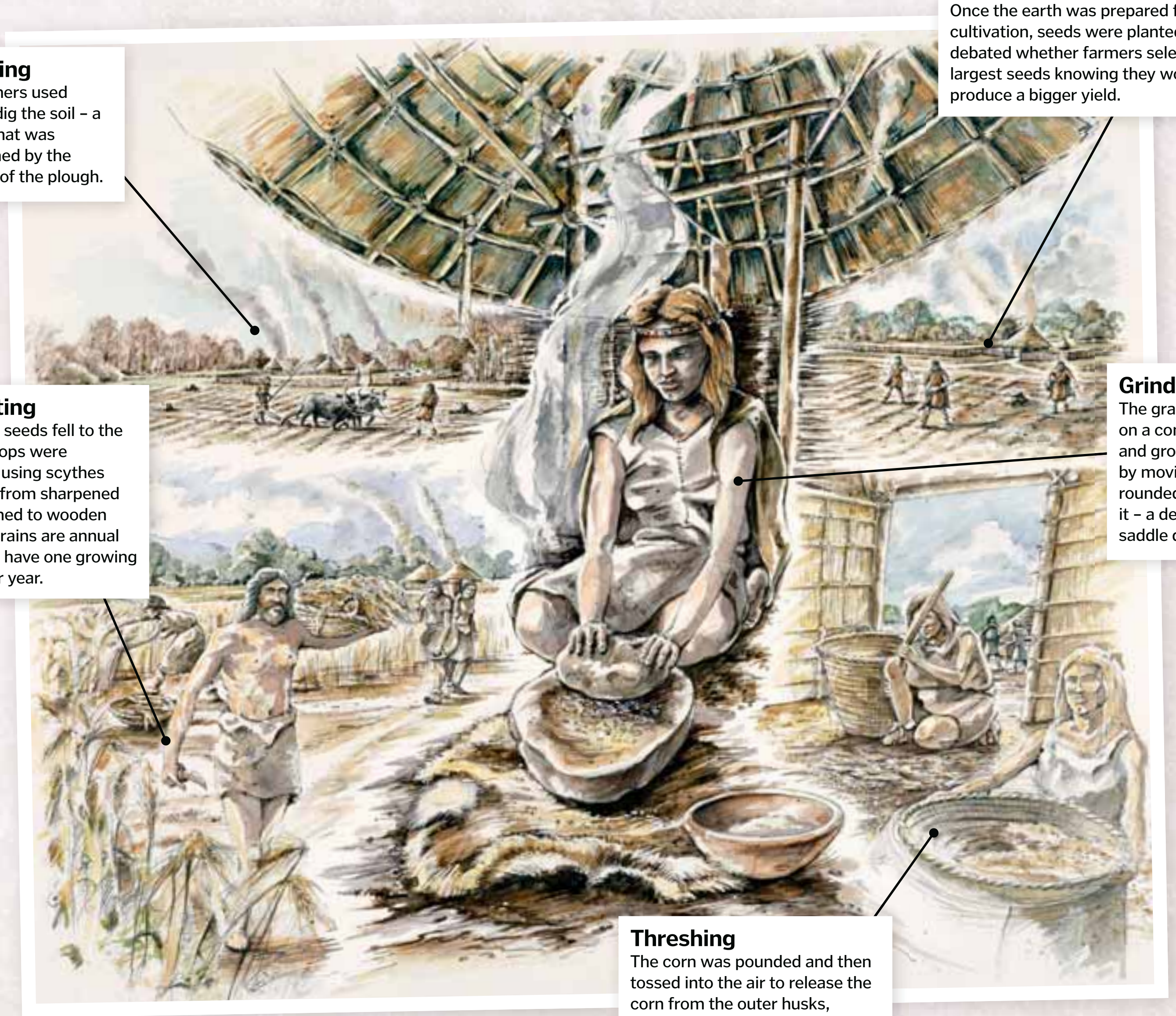


An artist's impression of a Neolithic site at Windmill Hill, in what is now Wiltshire, UK

There were no trees on the Orkney Islands, so settlers built their homes and furniture from stone

Grain production

This food staple has been enjoyed by cultures all over the world for thousands of years



Ploughing
Early farmers used sticks to dig the soil – a process that was transformed by the invention of the plough.

Sowing seeds
Once the earth was prepared for cultivation, seeds were planted. It's debated whether farmers selected the largest seeds knowing they would produce a bigger yield.

Harvesting
Before the seeds fell to the ground, crops were harvested using scythes fashioned from sharpened flint attached to wooden handles. Grains are annual plants and have one growing season per year.

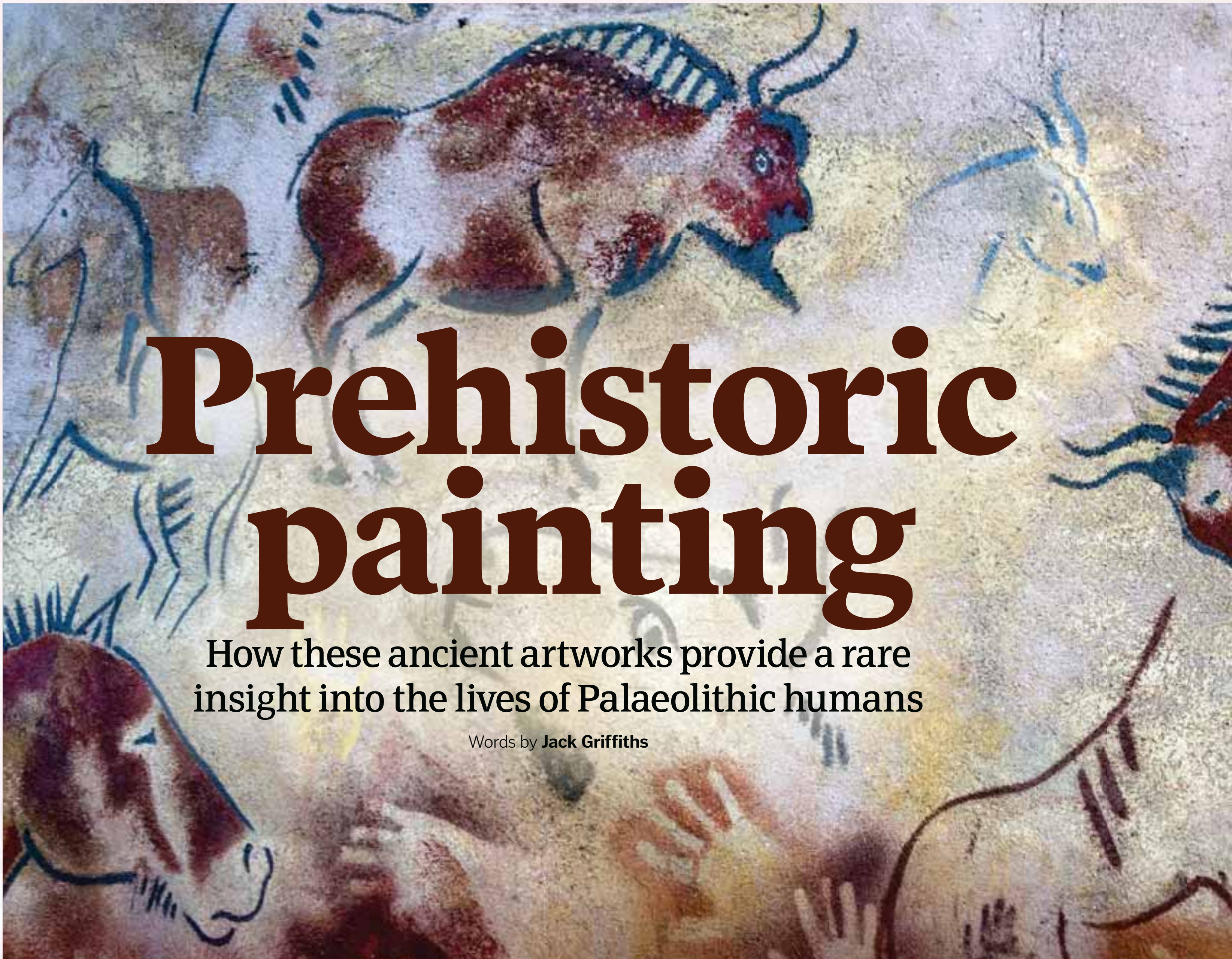
Grinding
The grain was put on a concave stone and ground down by moving a rounded stone over it – a device called a saddle quern.

Threshing
The corn was pounded and then tossed into the air to release the corn from the outer husks, known as threshing.

Alongside taking care of their livestock, Neolithic farmers tended to their crops. They cleared the ground, sowed the seeds and harvested the crops according to the seasons. Cereal grains like barley and emmer wheat were among the first crops to be domesticated by farmers in the Fertile Crescent, and later peas, lentils and flax. The latter was also used to make linen, using hand-spindles to process the fibres. Eventually, these wild plants evolved to depend on humans for seed dispersal, losing the ability to drop their seeds on the ground. Domesticated crops also grew much larger over time – maize seeds, for example, are 15 times bigger than their wild counterparts – either through natural selection or because farmers bred from the largest plants. Exactly how crops evolved and yields increased is something modern-day scientists are striving to understand, as food sustainability becomes an ever-pressing issue.

However, despite population sizes being tiny compared to more than seven billion people on the planet today, fear of famine plagued farming communities. It would have driven them to work harder to create food surpluses that were essential for survival. Regular surplus gave rise to larger societies, and different roles began to emerge, such as toolmakers and butchers. Eventually, there was a need for warriors to protect the land from wild beasts and outsiders looking to steal their wealth. Communities also sought to ensure their good fortune in other ways, building places of worship to appease the gods, and priests gained in significance as they prayed for good rain and crops.

As men took on these leading roles, inequality grew not only between the sexes but also between social classes. The farmers and craftsmen who were vital to the success of these early settlements eventually found themselves at the bottom of the social ladder. They produced the surplus food but it was the elite who controlled it, as archaeological digs have revealed the largest houses were next to the grain storage. Farming is the oldest industry in the world, and these primitive steps into productivity, trade and governance directly influenced how we live today.



Prehistoric painting

How these ancient artworks provide a rare insight into the lives of Palaeolithic humans

Words by **Jack Griffiths**

Prehistoric cave paintings are believed to be among the first examples of human art. The remnants of images found in caves today provide archaeologists with a fascinating insight into the world of our Stone Age ancestors.

So how did they make the paint? Black paints could be made from a simple mixture of charcoal and a binder, such as saliva or animal fat. The earliest coloured paints were made from naturally occurring minerals (known as pigments) such as iron oxides, which were ground into a powder before being mixed with a binder. These pigments were in high demand, and some prehistoric artists may have travelled 40 kilometres or more to gather them.

To make a typical cave painting, an outline was scored on the wall with a sharp stone, then marked out with charcoal. The image could then be filled in with a coloured pigment paint, and shaded to make it three-dimensional.

The majority of cave paintings are illustrations of animals that roamed the land nearby, including lions, rhinos, bears and even sabre-toothed cats. Images of the humans themselves are much less common. One theory for this is that it was believed that the artwork was a link to a spirit world, and the depictions would increase luck when hunting. Campfires in the caves helped to give the impression that the painted creatures were alive, with the illustrations dancing on the walls. Outlines of human hands, also known as hand stencils, are a common sight among cave paintings, thought to be a sort of artist's signature.

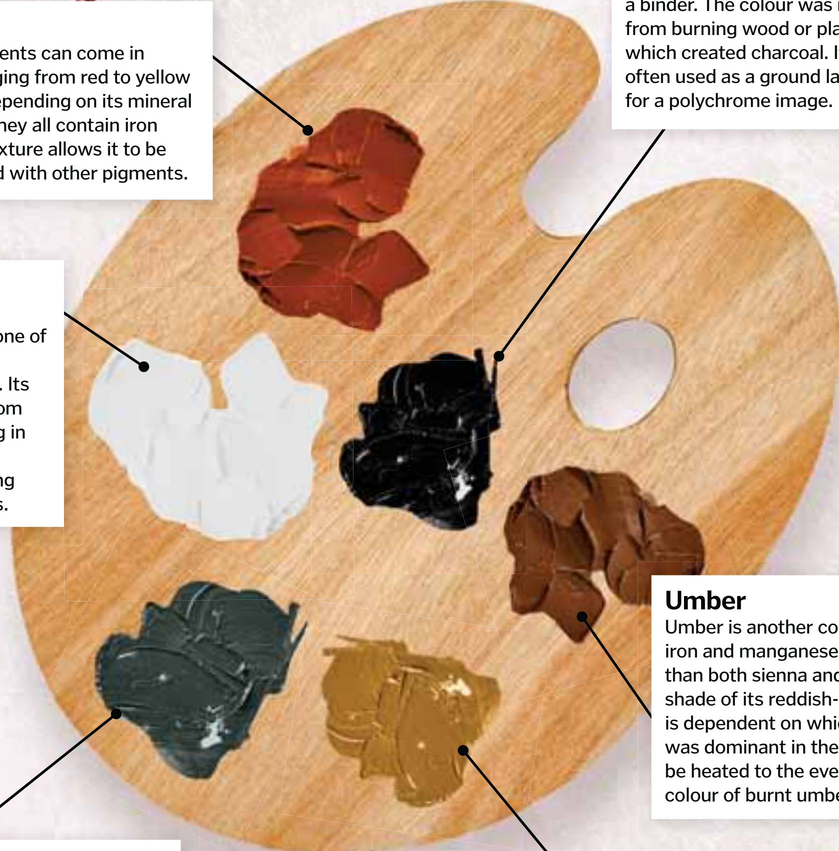
Scientists can estimate when a cave painting was made using radiometric dating, either using the rate of decay of the isotope carbon-14 in the pigments, or the rate of uranium decay in the surrounding rocks. Some paintings in Europe are thought to date back as far back as the Upper Paleolithic period, making them up to 40,000 years old. The European examples are perhaps the most well-known, but prehistoric cave art have been also been found in Africa, Asia and Australia, with (relatively) more recent examples in the Americas dating back nearly 10,000 years. Based on the discoveries so far, cave art seems to have become less popular as warmer climates allowed humans to begin settling outside of caves.

Discoveries of prehistoric art continue to fascinate us today and provide a unique insight into the culture of our distant ancestors.

In archeological terms, cave art is also known as 'parietal art'

The prehistoric palette

The colours and shades used to illustrate the Stone Age world



Ochre

Ochre pigments can come in shades ranging from red to yellow to brown depending on its mineral blend, but they all contain iron oxide. Its texture allows it to be easily mixed with other pigments.

Carbon black

Monochrome paintings were a simple mix of carbon black and a binder. The colour was made from burning wood or plants, which created charcoal. It was often used as a ground layer for a polychrome image.

Kaolin

Kaolin is a white-coloured clay and one of the Earth's most abundant minerals. Its name originates from the town of Gaoling in China, which is renowned for having rich kaolin deposits.

Umber

Umber is another combination of iron and manganese that is darker than both sienna and ochre. The shade of its reddish-brown colour is dependent on which mineral was dominant in the mix. It could be heated to the even darker colour of burnt umber.

Manganese oxides

One of the darkest colours used, manganese oxide could create shades that were brown, grey or black. Manganese deposits weren't common in caves adorned with artwork, so it's assumed painters would trek long distances to find a source.

Sienna

A mixture of iron oxide and manganese oxide, raw sienna is a pigment with a yellow-brown colour. When heated, it turned into burnt sienna, which is darker in tone and redder in colour.

Green and blue

Cave art typically features red, brown, yellow and black, but none of the paintings, it seems, included blue or green. This can be explained in part by the lack of natural pigment sources for these shades. In the Palaeolithic period, obtainable blue-coloured minerals were rare, especially in Europe. Blue was used in later eras by the ancient Egyptians, who used powdered azurite to make blue-coloured jewellery. The omission of green shades is more difficult to comprehend, as green coloured minerals like malachite and terre-verte were abundant. One of the reasons given for the lack of green colour is that it may have simply not shown up as well as red or brown does under fire or torchlight.

Left: Clay ochre could be red, yellow or brown, but not blue or green

Hand stencils

The techniques used to create the perfect prehistoric hand silhouette

1 Tools for the job

To create a hand stencil, researchers think that prehistoric humans used hollow bones or reeds to blow paint through, and a shell to hold the paint in. The pigment used to make the paint was ground into powder and could be sourced from various minerals.

2 Making the paint

The powdered pigment was mixed with a binder in the shell using the reed or bone. Researchers trying to recreate prehistoric hand prints found that to make a paint thin enough to spray, the Palaeolithic painters likely used water as a binder.

3 Creating the stencil

The artist placed one hand on the wall, held one of the reeds/bones in their mouth, and held the shell and second tube (dipped in the paint) in their other hand. Blowing through one tube across the top of the other created a cloud of colour spray on the wall.

4 Finishing touches

When the artist removed their hand from the wall, they left a silhouette with colour all around it. More colours could be added with brushes, or a charcoal outline could be drawn around the hand. Bumpy walls could also help create a 3D effect.

Whose hands were they?

Experts can determine the gender of the person who made a stencil with over 90 per cent accuracy. The technique that is used is part of a study called geometric morphometrics. Digital versions of modern male and female hand stencils were made and used as a template when measuring those of prehistoric hands. The hands were then compared based on palm shape, which has been found to be a more useful indicator of gender than just measuring finger length and hand size. The study reinforced that both genders would often produce stencils. Researchers can also make an educated guess regarding the handedness of the artists, as the hand that is on the wall would most likely be their weaker side, and the dominant hand would be the one used to hold the pigment.

Hand stencils in Cueva de las Manos (Cave of Hands) in Argentina, created between 13,000 and 9,000 years ago

The world's weirdest pigments

Our artistic ancestors were quite resourceful

Mummy brown

A hugely popular pigment during the 16th century, this was made from the remains of ancient Egyptian mummies. Mixed with myrrh and white pitch, it made a reddish-brown colour.

Tyrian purple

This pigment was made from a dye extracted from murex shellfish. A symbol of imperial authority in the Roman Empire, it was used to colour the emperor's toga.

Lead white

Long before it was known to be poisonous, lead white was used as a paint pigment and also in makeup. One theory is that it contributed to Van Gogh's deteriorating mental health.

Uranium yellow

This yellow-orange pigment was used to create coloured glass and glazes for ceramics. However, this stopped when it was found to be a radioactive and highly toxic substance.

Carmine

Carmine is a deep red colour that has long been associated with royalty and nobility. It is made from the carminic acid that oozes out of some species of crushed beetles.

Cave art across the world

The best examples of parietal paintings across the globe, from France to Australia

LASCAUX

France / 18,000 - 13,000 BCE

With hundreds of paintings and drawings and over 1,500 engravings, Lascaux is one of the best sites for prehistoric art on Earth. The caves include depictions of bison, mammoths, aurochs, lions and wolves among others.

PETTAKERE CAVE

Indonesia / 38,000 BCE

These Indonesian paintings are believed to be proof of prehistoric island-hopping in southeast Asia. The cave includes what are believed to be the oldest hand stencils on Earth.

CUEVA DE LAS MANOS

Argentina / 13,000 - 9,000 BCE

The Cave of Hands plays host to some of the oldest known cave paintings in the Americas. The artwork varies from hunting scenes to hand stencils and is red or black in colour.

KIMBERLEY

Australia / 50,000 - 5,000 BCE

Known as the Bradshaw or Gwion Gwion paintings, the age of the art itself is difficult to determine, but it's possible that this cave is home to some of the oldest artwork of human figures in the world.

"Some paintings in Europe are thought to be up to 40,000 years old"

BLOMBOS CAVES

South Africa / 100,000 - 70,000 BCE

Archaeologists have unearthed the remains of what appears to be a rudimentary paint workshop in these caves. They found engraved blocks of ochre, shell 'palettes', bone 'spatulas' and grinding equipment.

Depictions of humans in prehistoric cave art, such as those in the Bradshaw paintings, are rare

MESOPOTAMIA

THE CRADLE OF CIVILISATION

Discover how society as we know it began in a small region of modern-day Iraq

Words by **Frances White**

The ancient region of Mesopotamia has fascinated, enthralled and perplexed historians and scientists for thousands of years. Mesopotamia was not like the ancient empire of Greece, or even Egypt, because it was not a united nation. Made up of a vast collection of varied cultures, city-states and beliefs, Mesopotamia was a land of multiple empires and diverse civilisations. It is perhaps thanks to this variety that Mesopotamia gave birth to what we recognise as civilisation today. The list of Mesopotamian innovations is endless, and it is difficult to contemplate how modern life would be without them. Mesopotamia was home to the first ever cities, writing took form there and the oldest wheeled vehicles in the world were found in Mesopotamian ruins. Animals were domesticated, humanity came leaps and bounds in agriculture, innovative new tools were crafted, weapons were swung and wine was drunk. Mesopotamians were the first people to study the night sky, track the Moon and declare that there were 60 minutes in an hour, and 60 seconds in a minute.

Mesopotamia was driven by religion, and it was one of the few things that united the lands that made up the region. From this religion sprang customs, moral codes and social hierarchy. In many ways the Mesopotamians were ahead of their time, as women were regarded as individuals in their own right, free to own land, file for divorce and run businesses.

The Mesopotamian version of the Creation story declared that the world was formed when the gods achieved victory over the forces of chaos, and the same could be said in the creation of Mesopotamia itself. Mesopotamia, with its kings, taxes and trade, was a triumph of man's ability to conquer and thrive, and it set the blueprints for countless cities, countries and empires that followed.

SUMER

5400 BCE
The city of Eridu is founded; it is considered the first true city in the world.

3600 BCE
Writing first emerges in the form of cuneiform. Reeds are used to make marks in wet clay.

3500 BCE
Religion is first referenced in writing, in the form of Sumerian cuneiform tablets.

2334-2218 BCE
Sumer is conquered by Sargon the Great and comes under the rule of the Akkadian Empire.

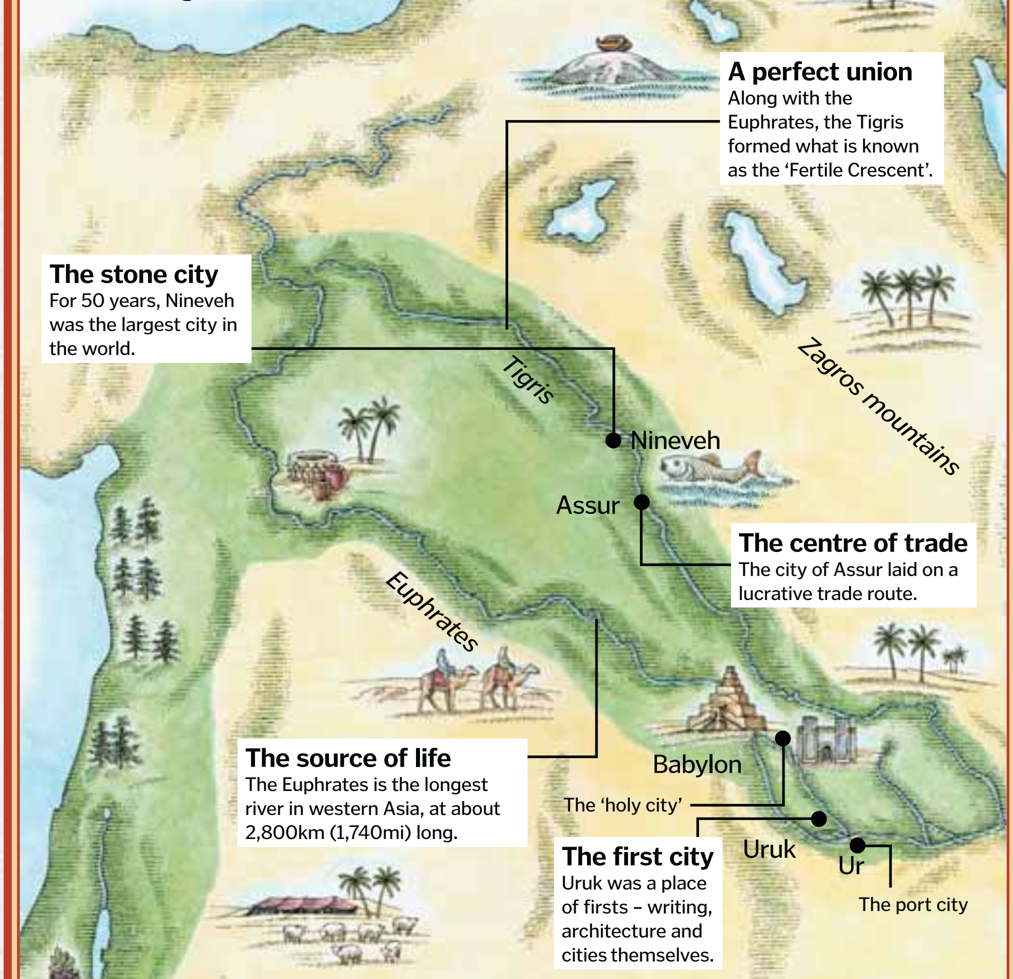
What it was like to live there

The word 'Mesopotamia' means 'between the rivers', which literally describes the location of the region. Mesopotamia lay between the Tigris and Euphrates rivers, which today flow through modern day Turkey, Iraq and Syria. All the regions of Mesopotamia experienced different geography, which led to variation in how people there lived. Lying between two rivers had some risks as the land was subject to frequent and unpredictable flooding, which could play havoc with farmers' crops. These floods went hand in hand with periods of drought. However, the swelling rivers helped to create very fertile soil that supported plants even with minimal rainfall, and allowed boats to be used as a quick means of transportation. Mesopotamians became skilled farmers and traded their crops for resources they were lacking, such as building materials like wood, metal and stone. The people took advantage of the ready supply of water by building canals to support the trade network and were able to flourish in spite of the lack of natural resources in some areas.

On the map

The land of plenty

Mesopotamia's unique geography enabled cities and civilisations to rise from the ground



"Mesopotamia, with its kings, taxes and trade, was a triumph of man's ability to conquer"

The rise of civilisation

Three of the major cultures that arose in Mesopotamia and influenced society

SUMERIANS

Sumer was the southernmost region of Mesopotamia, comprising modern day southern Iraq and Kuwait. Sumer was first inhabited in approximately 4500 BCE, or possibly even earlier. It is in Sumer that the first cities in the world were established, starting with Uruk. Sumerians believed that their cities represented god's triumph over chaos.

BABYLONIANS

With its name meaning 'gate of the gods', Babylonia lay in central southern Mesopotamia, which is modern day Iraq. The earliest days of Babylonia are a mystery lost to rising sea levels, but from 1792 BCE the famous king Hammurabi came into power and the city of Babylon - built upon the Euphrates river - became the beating heart of Mesopotamia.

ASSYRIANS

Located in the Near East, the ancient kingdom of Assyria comprised of regions of Iraq, Syria and Turkey. Assyria was the driving force of technological, scientific and warfare developments in Mesopotamia. The Assyrian empire gradually expanded to unite most of the Middle East, increasing their power and wealth to become a formidable power in the region.

2150-1400 BCE
The Epic of Gilgamesh is written. The poetic work stands as one of the oldest pieces of western literature in existence.

2100 BCE
The Sumerian King List is created, establishing the idea of kingship as a divine institution.

1800 BCE
All the cities of Sumer, and of Mesopotamia, are united by Hammurabi, who makes Babylon his capital.

1750 BCE
A combination of invasion, migration and the sacking of Ur brings an end to the Sumerian civilisation.

The world's first cities

With a reliable source of food, people gathered together in Mesopotamia and formed the very first cities

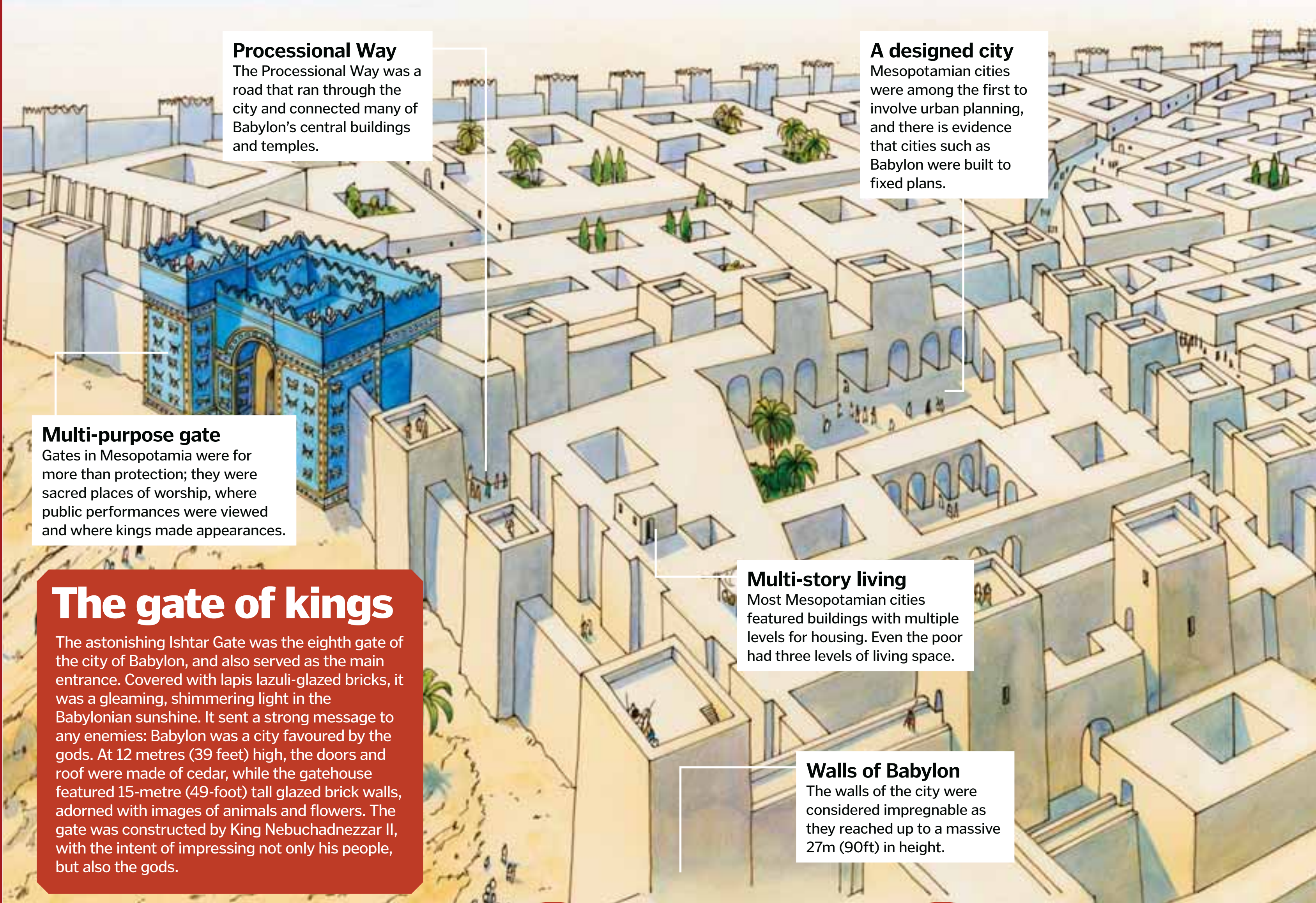
Mesopotamia was home to some of the very first cities in existence, leading many to link it to the birth of true civilisation. The origin of these cities is still unknown today, though many theories exist. One suggestion is that the development and building of temples created a place where people would gather, and thus served as points of contact between different groups of people.

Others believe that people sought sanctuary from natural disasters. As the Mesopotamians were able to develop technology to help them control the nearby rivers, such as levees, they could ensure a good crop. They had no need to be nomadic, and were able to settle in one place comfortably. It is for this reason that all the early cities were built along the two major rivers.

The moment the Sumerians began to form these cities, it forever altered human history. People went from being ruled by nature, to attempting to control it. By 4500 BCE the first recorded city rose in the form of Uruk. However, the only urban structure at this point was the temple, which regulated all economic and social matters.

The central purpose of these early cities was to help regulate trade, as southern Mesopotamia was reliant on outside resources. This need for trade and resources encouraged the spread of urbanisation. However, communication between the cities was difficult, and so each city developed into an individual city-state. This led to territorial disputes and, inevitably, war.

In order to keep their cities protected, the Mesopotamians built fortifications, and walled cities rose. Migration to these cities increased, and more buildings were erected. Cities gradually expanded and rulers were proclaimed, who then began looking outwards for trade and conquest.



Processional Way
The Processional Way was a road that ran through the city and connected many of Babylon's central buildings and temples.

A designed city
Mesopotamian cities were among the first to involve urban planning, and there is evidence that cities such as Babylon were built to fixed plans.

Multi-purpose gate
Gates in Mesopotamia were for more than protection; they were sacred places of worship, where public performances were viewed and where kings made appearances.

Multi-story living
Most Mesopotamian cities featured buildings with multiple levels for housing. Even the poor had three levels of living space.

Walls of Babylon
The walls of the city were considered impregnable as they reached up to a massive 27m (90ft) in height.

The gate of kings

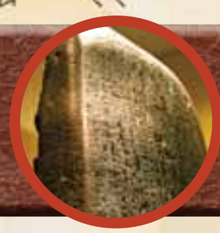
The astonishing Ishtar Gate was the eighth gate of the city of Babylon, and also served as the main entrance. Covered with lapis lazuli-glazed bricks, it was a gleaming, shimmering light in the Babylonian sunshine. It sent a strong message to any enemies: Babylon was a city favoured by the gods. At 12 metres (39 feet) high, the doors and roof were made of cedar, while the gatehouse featured 15-metre (49-foot) tall glazed brick walls, adorned with images of animals and flowers. The gate was constructed by King Nebuchadnezzar II, with the intent of impressing not only his people, but also the gods.

BABYLONIA

1894 BCE
The first Babylonian dynasty emerges; this Amorite dynasty forms a small kingdom including the city of Babylon.

1792 BCE
Hammurabi begins his reign as ruler of Babylon. He transforms it from a tiny town to a powerful city.

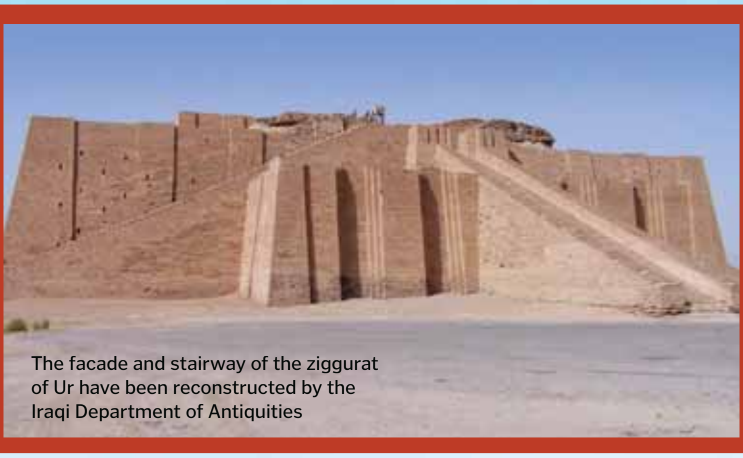
1792-1750 BCE
During his reign, Hammurabi introduces some of the earliest examples of laws in the form of the Code of Hammurabi.



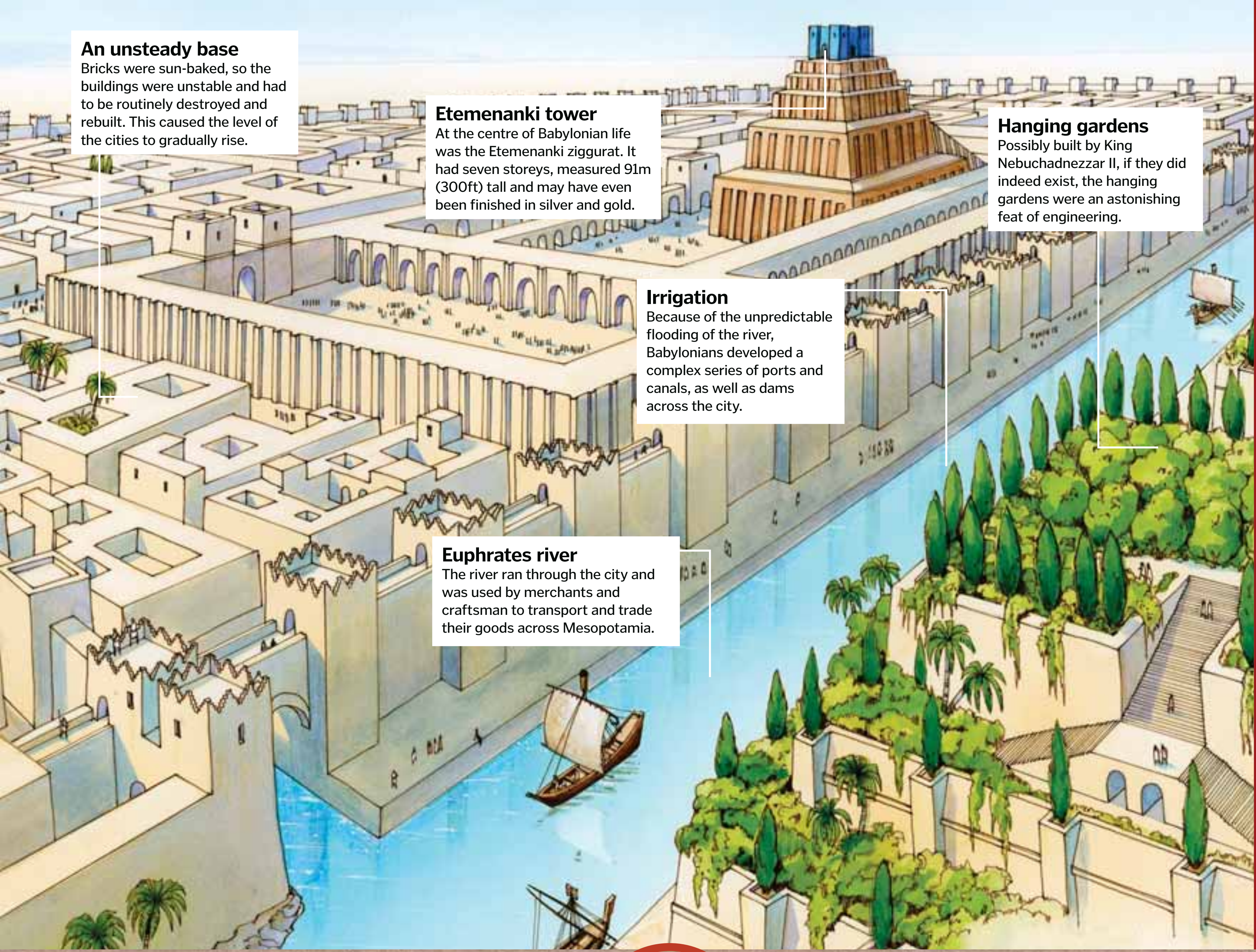
1755 BCE
Hammurabi conquers and unites Mesopotamia under his rule, and Babylon becomes known as a holy city.

Towering temples

Ziggurats were temples built on high, stepped platforms. Although they originated in Sumerian cities in 2000 BCE, they gradually spread to all of Mesopotamia, including Babylonia and Assyria. The stepped towers were mainly constructed from sun-dried bricks layered between reeds. It is believed that many ziggurats featured a shrine at the top, but no examples of this remain. Although their exact purpose cannot be verified, it is known that ziggurats were linked to religion, and each ziggurat was connected to large temple complexes. There was a belief in Mesopotamia that the gods resided in the Eastern mountains; therefore building high temples would more closely connect the people with god, linking heaven with Earth. A practical purpose of the high platforms was to escape any rising floodwater that rushed into the lowlands. The structure of the ziggurat, which was accessible only by three stairways, also ensured that the rituals conducted within remained secret and sacred.



The facade and stairway of the ziggurat of Ur have been reconstructed by the Iraqi Department of Antiquities



An unsteady base
Bricks were sun-baked, so the buildings were unstable and had to be routinely destroyed and rebuilt. This caused the level of the cities to gradually rise.

Etemenanki tower
At the centre of Babylonian life was the Etemenanki ziggurat. It had seven storeys, measured 91m (300ft) tall and may have even been finished in silver and gold.

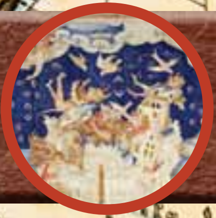
Hanging gardens
Possibly built by King Nebuchadnezzar II, if they did indeed exist, the hanging gardens were an astonishing feat of engineering.

Irrigation
Because of the unpredictable flooding of the river, Babylonians developed a complex series of ports and canals, as well as dams across the city.

Euphrates river
The river ran through the city and was used by merchants and craftsman to transport and trade their goods across Mesopotamia.

Circa 1750 BCE
Babylonian mathematicians introduce the concept of place value in numbers. Astronomers also name the planets and constellations.

1595 BCE
Babylon is sacked by the Hittite king Mursili I. This marks the beginning of the Babylonian 'dark ages'.



1595–1155 BCE
The Kassite dynasty rules over Babylonia. They rename Babylon 'Kar-Duniash' but it continues to serve as the capital of the kingdom.

1225 BCE
The Assyrian ruler Tukulti-Ninurta I destroys the armies of Babylon and sacks the city. He goes on to become king.

Seven ways Mesopotamia changed the world

The phrase 'the foundations of civilisation' is often used while talking about Mesopotamia. But what exactly does this mean? Is civilisation simply people living together, or does it involve more? Agriculture had emerged by 8000 BCE, and art was produced for thousands of years before Mesopotamia rose. However, Mesopotamia took these aspects of human culture and transformed them into civilisation, as we know it today. Brought together by a common goal – to find food – the Mesopotamians developed some of the earliest writing known to man. This writing was borne out of necessity to record accounts and crop yields. However, it later developed to represent more abstract ideas. As people were gathered together, spiritual practices were also refined, and the population began to share a common belief system. With this established, the priests, who claimed to be able to communicate with the gods, took their place at the top of the social hierarchy, and slowly a class system developed. This emphasis on religion inspired moral codes for the people to follow, which led to formal rules and in turn, punishment for those who disobeyed. A steady food supply meant the Mesopotamians could pursue other aspects of life, such as technology and science. They made ground-breaking advancements in the areas of mathematics and medicine. However, this social structure also revealed the darker aspects of humanity, such as war, slavery and expansion, and with so many people gathered together, diseases spread rapidly. As the civilisation developed, it inevitably had an influence on other cultures. It is believed that Babylonian astronomy influenced Greece, India and even China. The early Mesopotamian codes of laws also had a profound effect on lawmaking in the Near East, and the introduction of taxes and a standing army influenced countries worldwide. In fact, historians are still exploring the huge impact that Mesopotamia had on the ancient world, and the world we live in today.

The creation of writing

Writing began in Mesopotamia towards the end of the 4th millennium BCE as a way to record crucial information about crops and taxes in pictorial form. These early tablets developed into a script, which bears close resemblance to writing today. This system of writing is commonly known as cuneiform and comprised of wedge shaped marks in clay. Gradually the number of characters used in cuneiform decreased from 1,000 to around 400, which ensured more clarity in the script. By 2500 BCE cuneiform was developed enough to portray emotions such as fear and hope.

The word cuneiform itself simply means 'wedge-shaped'

The remains of the Code of Hammurabi were discovered in 1901 in excellent condition

Health care

Medicine in Mesopotamia involved a combination of religious ritual and physical treatments. Mesopotamia had specific doctors with their own offices, beds and equipment and generally fell into two categories – the ashipu, who practised religious medicine, and the asu, who used herbal remedies; generally these two doctors would work together to treat an ailment. The ingredients used in the various treatments ranged from turtle shell and snakeskin to figs and seeds. Mesopotamian doctors recorded their methods of treatment and diagnosis in medical texts, such as the Treatise of Medical Diagnosis and Prognosis.

Thou shalt obey

Law codes as we know them today were first created in Mesopotamia. One of the earliest examples of Mesopotamian laws is the Code of Hammurabi. The code features 282 laws dealing with a huge variety of issues, from marriage to theft, in great detail. For example, if a man rents a boat to a sailor and it is wrecked, the sailor has to give the man a new boat. Although it is the most well-known, the Code of Hammurabi was pre-dated by other law codes, such as the code of Lipit-Ishtar and those written by the Sumerian king Ur-Nammu, who described the purpose of his laws as protecting the weak from the mighty.

ASSYRIA

2600 BCE
The city of Ashur, capital of Assyria, is founded, along with other Assyrian cities.

1813-1776 BCE
Shamshi-Adad I rules Assyria. He expands the empire, secures Assyria's borders and builds up a powerful army.

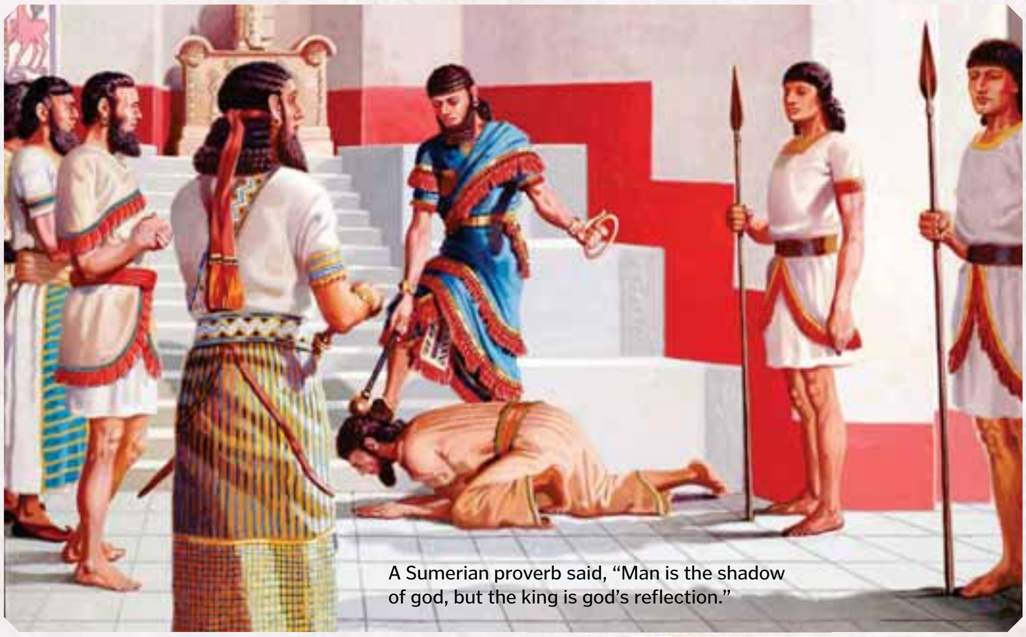
1472 BCE
The kingdom of Mitanni, a powerful northern Mesopotamian state, annexes Assyria and the land loses its independence.

1365-1330 BCE
Ashur-uballit I defeats the Mitanni, and under his leadership, Assyria develops as a powerful and rapidly expanding empire.

1244-1208 BCE
The warrior king, Tukulti-Ninurta I, reigns. Assyria expands to its greatest extent and defeats the ruler of Babylonia.

Only the strong shall lead

Mesopotamia was made up of several city-states which each had their own leaders and government, with kings ruling over individual regions. This led to a lot of internal fighting between different kings for land and resources. The first kings were the leaders of armies, who then went on to continue to lead during peacetime. Because of the strong emphasis on religion, the kings often served as high priests and therefore were linked to the divinity of god, and claimed to be god's representatives on Earth. Some of these kings, such as Sargon, sought to unite many of the city-states under one leader and capital.



A Sumerian proverb said, "Man is the shadow of god, but the king is god's reflection."

Learn more

To learn more about the wonders and innovations of ancient Mesopotamia, explore the British Museum website: **www.mesopotamia.co.uk**

Mesopotamian money

Mesopotamians used silver rings thousands of years before the first coins were made. In around 2500 BCE a 'shekel' of silver became the currency of Mesopotamia, with one month of labour being worth one shekel, and a slave worth between ten and 20. Prior to this, clay tokens in a variety of sizes and shapes were used for trade and barter. There were at least 16 different types of these tokens that represented various things, such as rope, sheep's milk, perfume and honey.

This Carthaginian shekel from 310-290 BCE is similar to the Mesopotamian shekel

The Standard of Ur, an artefact dating from around 2600 BCE, depicts wheeled chariots being used in battle

The basis of time

The Mesopotamian's were trailblazers in their concept of time. They were the first in recorded history to use a base 60 numerical system for measuring it with. This led to our 60-second minute and 60-minute hours today. Many believe that it was this base 60 system that helped the Babylonians make such impressive advances in mathematics, as 60 has many divisors. They also used a lunar calendar, which comprised 12 lunar months, at an average of 29.5 days each. This left the Mesopotamians short by around 11 days a year, so they added seven months in each 19-year period to keep the seasons aligned.

The Royal Game of Ur, one of the oldest in the world, was played with early Mesopotamian mathematics

A wheely late invention

Surprisingly, the wheel was actually invented at a rather late point of human history, with the oldest example from Mesopotamia dating to 3500 BCE, in the Bronze Age. It is likely that the wheel was developed individually by different cultures around the same time. Evidence shows that Mesopotamians used this invention for pottery first, before adapting the design for transport with chariots. Wheels did offer advantages to transportation, but they took a great deal of time to make as smooth as possible, so sledges were still commonly used alongside the wheel.

1000 BCE
Assyria establishes the first cavalry force. As this is before the invention of saddles, the warriors ride bareback.

668-627 BCE
During his reign, King Ashurbanipal establishes a huge library, housing a collection of thousands of clay tablets.

612 BCE
Many Assyrian cities, including Ashur and Nineveh, are sacked and destroyed by a combined force of Medes, Persians and Babylonians.

50 GREATEST INVENTIONS

From the wheel to the 3D printer, we pick 50 of history's most significant innovations that have shaped the modern world

Words by **Rob Jones**

What is it to be human? That question is hard to answer, but one thing that most would agree plays a large part in it is our creativity. Machines – even revolutionary ones – lack the ability to think outside the box, or to add two and two together and make five. They can often outperform us in many tasks – both physically and mentally – however the creative element that led to their own existence remains elusive.

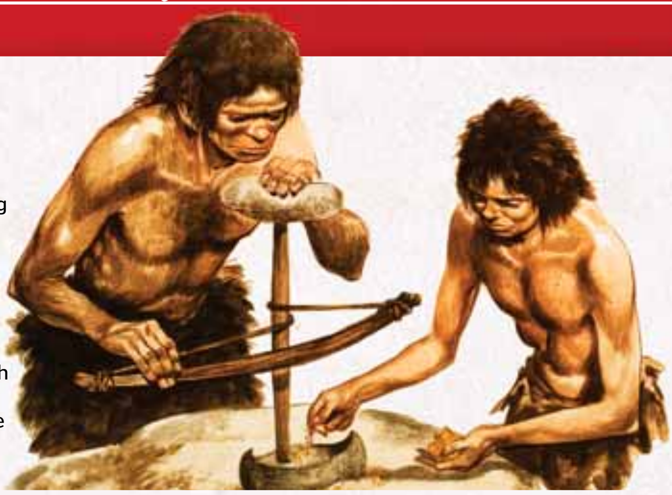
And so it has been throughout time. Human ingenuity has led to the creation of thousands upon thousands of tools, machines, systems, processes and materials that have made our lives easier and helped us better understand the world. From the wheel to the refrigerator, printing press to magnetic compass, humanity has always pushed its creativity to the limit, building devices that – while sometimes seeming insignificant – have gone on to change the world in amazing ways. Of course, not every creative spark has led to the electric light bulb or microscope, but we can nevertheless always learn from our mistakes – sometimes even more than our successes.

Here are just 50 of the millions of inventions that have been produced due to our insatiable hunger to make our lives that little bit easier. You never know, perhaps they'll inspire you to think up some innovations of your own…

1. Basic tools

2.6 million years ago

Early humans discovered the use of sharp stones early on in the Palaeolithic period and, after identifying their ability to cut and skewer, began artificially sharpening stones of their own accord and fashioning them into primitive weapons. This tool-making evolution enabled us to perform a wide array of tasks that before would have been impossible – or at least much more difficult – such as hunting, skinning animals and cutting wood. The earliest stone tools discovered to date are from 2.6 million years ago; they were unearthed in Ethiopia.



4. Maps

6500 BCE

From a modern perspective it's hard to imagine a time when maps didn't exist, however for thousands of years that was the case, with humans living without them up to around 6500 BCE when the art of cartography emerged in Ancient Babylonia. One of the earliest examples is a wall map found in Çatalhöyük (now in Turkey),

6. Glass

4500 BCE

Just think, where would we be without glass? Living in much colder or darker homes, that's for sure. Indeed, since its invention some 4,500 years ago in the Bronze Age Middle East, the use of glass became more and more widespread. By the time of the Ancient Romans, glass was no longer a luxury commodity, used by many for bottles and jewellery. Today, this world-changing material features in virtually every building and vehicle on Earth.

7. Glue

4000 BCE

While these days we have artificial man-made adhesives, simpler natural glues have been used for thousands of years. Ancient Egyptian carvings that are over 3,000 years old

2.6 MYA

2. Basic agriculture

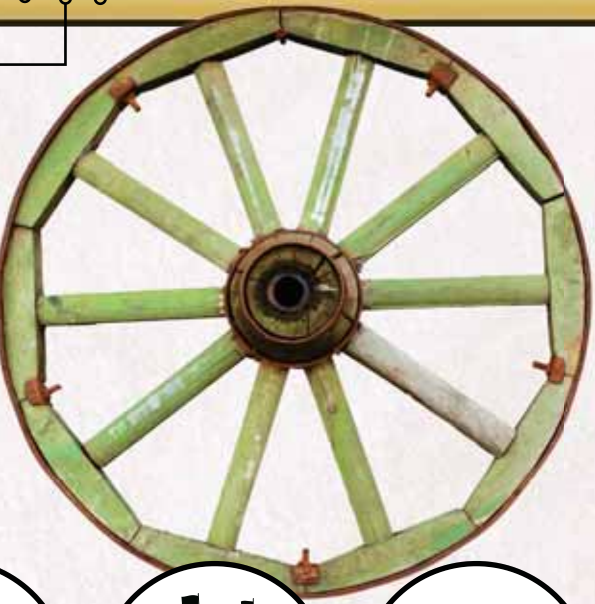
12,000 years ago

The invention of basic farming tools and techniques was vital to the development of civilisation, allowing us to transition from small hunter-gatherer groups into larger, more advanced trading societies. Evidence suggests that around 12,000 years ago planned cultivation was in effect, with specialised tools such as harvesting sickles, while advanced agricultural techniques like irrigation followed later in Mesopotamia circa 6000 BCE.

5. Wheel

5150 BCE

One of the greatest inventions of all time, the wheel has not only stood the test of time – with the oldest discovered carbon dated to around 7,150 years ago – but transformed every society or industry it has touched. From farming fields 1,000 years ago through to commuting miles into a 21st-century metropolis, the invention of the wheel has made all our day-to-day lives easier

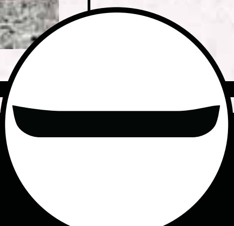


EVOLUTION OF...

3. Boat

7500 BCE

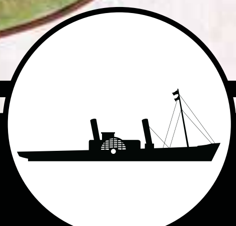
With 70 per cent of Earth's surface covered in water, there was always a demand for water-going transport – something that was first met in the mid-eighth millennium BCE. The earliest boats were dugouts: simple tree trunks hollowed out to form canoe-like vessels. But over the following centuries and millennia, they grew in size and complexity dramatically. Here we pull out some of the boat's evolutionary stages up to the present day...



Canoe
The inevitable evolution of the dugout, the canoe was fashioned around the world by peoples from the Americas, Europe and Oceania.

Chinese junk
Developed in the Han Dynasty (206 BCE – 220 CE), this was a wooden, ocean-going transport

Galleon
A multi-decked sailing ship used for transport, trade and combat, the 16th-century galleon became famous for its



Paddle steamer
Combining paddle-wheel propulsion and a steam engine, this became the most popular way to cross oceans in the

"The Ancient Romans used beeswax glues to fill the seams of their ships"

9. Weaving

3500 BCE

Weaving may not sound like a groundbreaking invention, but when the Ancient Egyptians mastered it back in the fourth millennium BCE, it revolutionised the way we dressed. This early weaving was undertaken on primitive, two-person looms that could only weave a fixed length of cloth. However, by the close of classical antiquity, dexterous horizontal and vertical weaving looms could be found throughout Asia, Africa and Europe (including Ancient Greece, as illustrated). Today, weaving is undertaken on a massive scale by large, shuttleless machines such as rapier and air-jet looms.

KEY PLAYERS

Leonardo da Vinci

1452-1519

This legendary Italian polymath is one of the greatest-ever inventors due to the massive catalogue of inventions he created in his lifetime. The extensive list includes many objects that are still in use today, such as hydraulic pumps, mortar shells, hang-gliders and machine guns.

2500 BCE

8. Alphabets

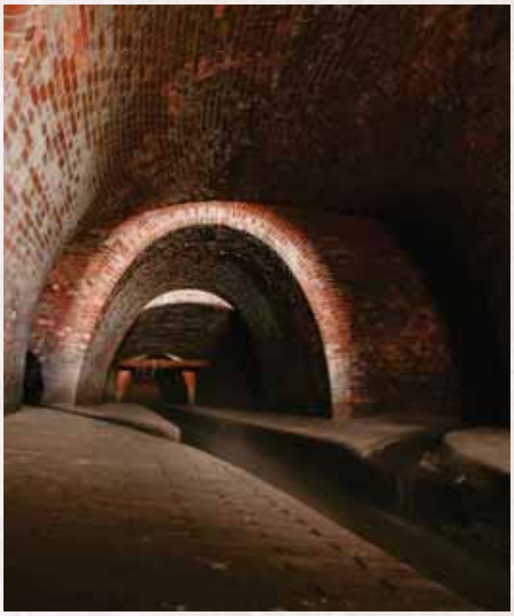
4000 BCE

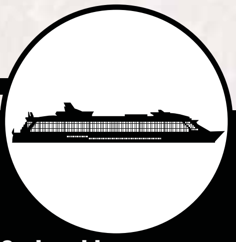
The phonetic alphabet is believed to have been devised around 6,000 years ago by the Canaanite peoples of the Middle East as a simplified version of Egyptian hieroglyphs. This language, which incorporated a mixture of the earlier hieroglyphic system and later Semitic letters, enabled the average person to write down their thoughts and feelings for the first time. Previous to this, the physical writing of information had been a highly restricted practice, typically the reserve of priests and the well educated. Today, all subsequent alphabets have descended in one way or another from this first phonetic system and are used to communicate the world over.

11. Sewage system

2500 BCE

The creation of the first sewerage system surely has to be one of the most fundamental life-bettering inventions of all time. Starting as simple, below-floor-level cesspits before evolving into brick-lined drains and, in more recent times, full-blown underground networks of tunnels and recycling centres, sewage systems have been an intrinsic part of civilisation since circa 2500 BCE. Excavated homes from the Indus Valley in Pakistan are some of the earliest to reveal the remains of connections to a large sewage drain.





Cruise ship

With the largest cruise ships capable of carrying over 5,400 passengers, today's vessels tend to resemble floating cities more than boats.

10. Soap

2800 BCE

Soap, in its most fundamental form, first emerged in Babylonia almost 5,000 years ago. This crude soap was a mixture of fat and ashes, which were boiled together in a big cauldron and then stored in clay pots. This emulsifying agent was later refined in Spain during the 19th century into the hard white soaps we are more familiar with today. Originally this new take on soap was made from olive oil and the ashes of the salsola plant.

12. Magnetic compass

200 BCE

It was the Ancient Chinese who first discovered the orientating effect of rare ore magnetite and, following this, they put it to use as a crude form of compass in the lodestone. It was more than 1,000 years later before a true navigational compass appeared – again devised in China. The compass was a remarkable milestone in navigation, removing the need for sailors to rely on landmarks and celestial bodies to plot a course and thereby mitigating the uncontrollable factors of overcast weather and darkness. The compass undoubtedly played a huge part in the Golden Age of Exploration during the 16th and 17th centuries.

13. Parchment

150 BCE

While papyrus scrolls and cuneiform tablets predated parchment, its creation was arguably far more important in the grand history of writing, as it paved the way to the development of the first book. Papyrus only came in scroll form and was relatively stiff, while parchment – being made from the scraped skins of animals – was smooth, flexible and more resistant to variable environments and atmospheres. This allowed multiple sheets of parchment to be sewn together into larger manuscripts.

17. Rocket

904

After the Chinese had invented gunpowder they soon created something called 'fire arrows'. These weapons were standard arrows with a tub of gunpowder strapped to the shaft that exploded on contact. By the early-13th century, fire arrows had evolved into rockets, with individual arrows carried at great speed by attached rocket tubes, very much like modern-day fireworks.

18. Spectacles

1286

Today there are many people around the world with some sort of eye deficiency, so it's a good job we have eyeglasses to help correct vision. This wasn't the case before the late-13th century, as prior to the invention of the spectacles in Italy the optical powers of lenses were poorly understood. Even after they were developed, only the richest visually impaired would have been able to afford a pair of specs to help them see.

19. Clocks

Late-13th century

While water clocks and, even earlier, sundials had been in use for centuries, it wasn't until the end of the 13th century that weight-powered mechanical clocks began to appear. Who exactly invented the first mechanical clock is lost in time – excuse the pun – but records show that complex escapements and mechanical clocks were becoming commonplace in church towers by the close of the 14th century in Europe. Since then, the accuracy of mechanical clocks has been consistently improved, doubling in accuracy about every 30 or so years on average.

200 BCE

14. Calendar

46 BCE

While the Sumerian lunar calendar had been in use since about 2000 BCE, the invention of the Julian calendar – a reform of the earlier Roman calendar – by Julius Caesar in 46 BCE proved to be one of the most resilient and well used of all time. Indeed, it wasn't until 1582 that it was superseded by the Gregorian calendar, which was introduced by Pope Gregory XIII. Today, the Gregorian calendar is internationally the most widely used calendar.

15. Gunpowder

800

Invented by Chinese alchemists, gunpowder is one of the deadliest-ever human creations. In its original form – a mix of potassium nitrate, charcoal and sulphur – it was used to power a fire lance, a primitive spear launcher made from a bamboo tube and reinforced with metal hoops. Through the Middle Ages its use became ever-more refined for shooting cannons and muskets.

"Gunpowder was [first] used to power a fire lance, a primitive spear launcher"

16. Windmill

800

The windmill was invented in eastern Persia during the ninth century. According to surviving documents, these early windmills had between six and 12 sails made up from reed and cloth matting and were used to either grind grain or draw up water – the latter typically as part of an irrigation system. The now-traditional horizontal-axle windmill (pictured) – such as those found in Holland – was invented much later, appearing in Europe during the 18th century. Today, windmills have declined in use, though their principles still apply to newer inventions such as wind turbines.

EVOLUTION OF…

23. Telescope

1609

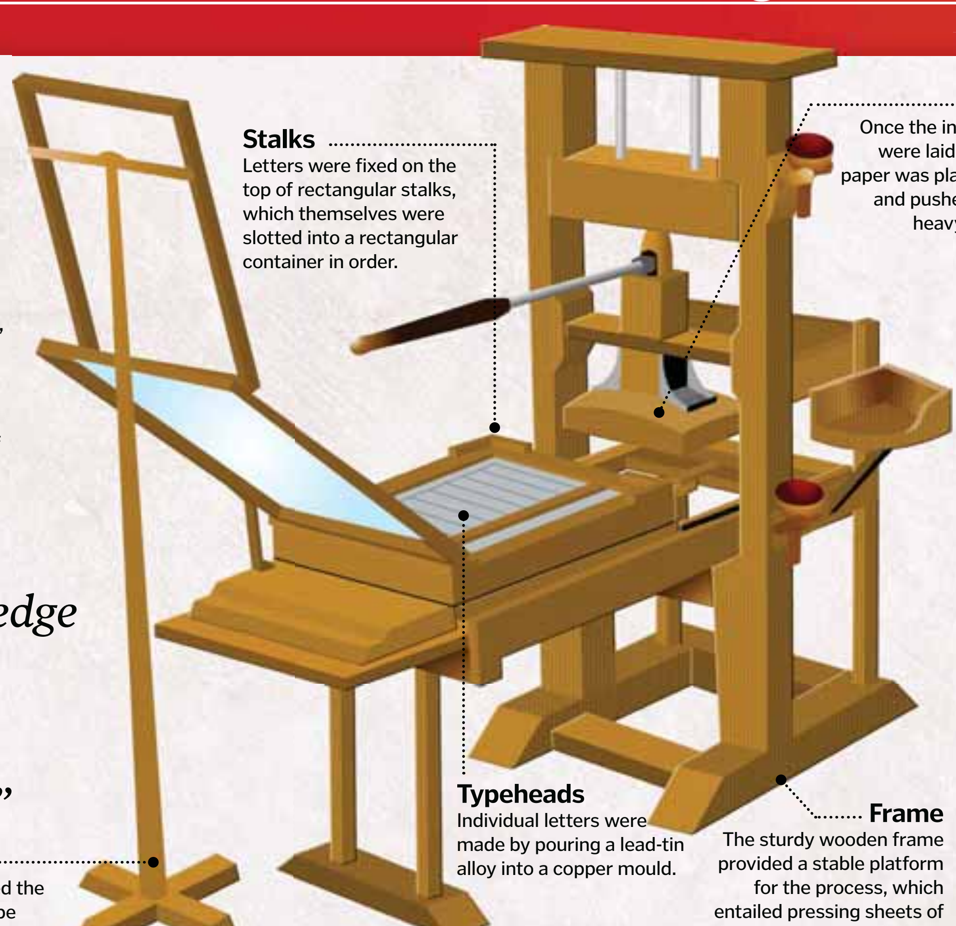
The invention of the telescope is generally now attributed to the German-Dutch lensmaker Hans Lippershey, but many have argued it was not until Galileo Galilei copied his designs and improved upon them in 1609 that the telescope, as we know it today, was born. Galileo's telescope reportedly offered 20x magnification and through it the astronomer discovered four of Jupiter's satellites and that the Sun was covered in spots. Since then, the telescope has evolved massively and today enables us to explore some of the very deepest reaches of space. Check out some of the key points in the telescope's development now…

20. Printing press

1450

Surely this is one of humankind's most edifying inventions. The printing press – built by Johannes Gutenberg in the mid-15th century – allowed documents and books to be produced quickly and cheaply in bulk, bringing literature to the masses. Indeed, this device wrenched the knowledge of the ages away from a minority of wealthy and learned scholars and placed it in the hands of the everyday person, inspiring many to go on and make world-changing inventions of their own.

"This device wrenched knowledge from a minority and placed it in the hands of the everyday person"



KEY PLAYERS

Archimedes of Syracuse

287-212 BCE

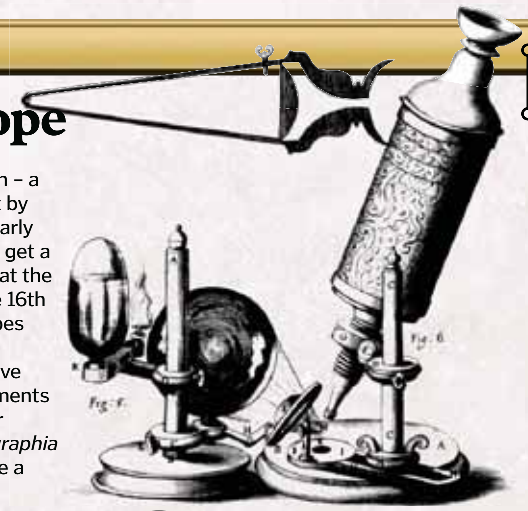
Not only was Ancient Greek polymath Archimedes (of 'Eureka!' moment fame) one of the greatest mathematicians of all time, but he was also one of the greatest inventors. A few of his best-known accomplishments include the Archimedes screw, the claw of Archimedes and the odometer. Archimedes was killed before his time during the Siege of Syracuse.

1609

21. Microscope

1590

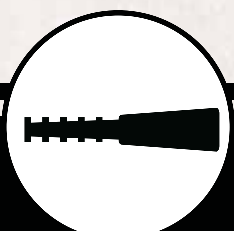
It wasn't until Zacharias Janssen – a Dutch lensmaker – realised that by inverting the lens structure of early prototype telescopes you could get a high degree of magnification that the microscope was invented in the 16th century. These initial microscopes were simple compound types, combining a magnifying objective lens with an eye lens. Advancements soon followed though and, after Robert Hooke published *Micrographia* in 1655, the microscope became a staple tool for any scientist.



22. Flush toilet

1596

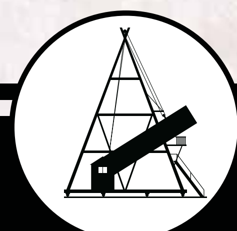
Toilets had been in use for centuries by the end of the 16th century, often with a sewage system. However, these toilets were in reality mere pits/holes, with no moving mechanisms in the waste removal process. That changed in 1596 when writer John Harington installed a flush toilet in his house in Kelston, England. The design used a special valve to let water out of a suspended tank and into the bowl, flushing away the waste.



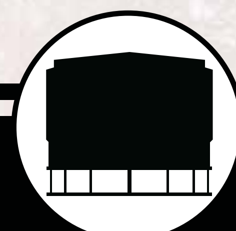
Lippershey telescope
A simple tube filled with a convex and concave lens, the original Dutch-made telescope offered a rather basic 3x magnification. Nevertheless, it was quickly sold throughout the Netherlands and much of Europe.

Galileo telescope
One of the most important in popularising these instruments, the Galilean telescope was the first to offer large magnifications of 20x and up. After Galileo showed his telescope to the Doge of Venice it took off all over the continent.

Newtonian telescope
Dissatisfied with flaws in refracting telescopes, Isaac Newton invented the reflecting telescope in 1668, presenting a second refined version to the Royal Society in 1672. Today, the majority of domestic telescopes are of the reflecting type.



Herschel's 40-foot telescope
British astronomer William Herschel built over 400 telescopes, but his largest was a 12-metre (40-foot) focal length reflecting telescope made in 1789. On the first night of using it, he discovered a new moon of Saturn.



Very Large Telescope
One of the most advanced and powerful telescopes that exists on the planet today, the European Southern Observatory's Very Large Telescope (VLT) array, based in Chile, is capable of imaging entire galaxies in phenomenal detail.

26. Vaccinations

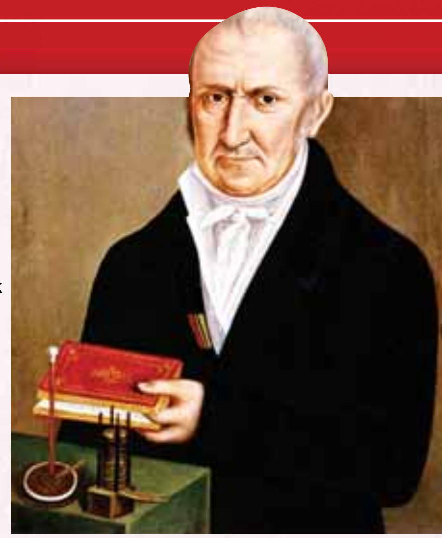
1796

Dying of smallpox was not a pleasant way to go, with a slow and painful death almost guaranteed. On the other hand, catching cowpox was only a minor inconvenience and, better yet, it prevented you from catching smallpox. English doctor Edward Jenner noticed this link and, after experimenting on some of the local dairy workers, published his results in 1798. He invented a vaccine that later became mandatory, though there were a lot of naysayers before his research was recognised.

27. Battery

1799

When Italian scientist Alessandro Volta made his voltaic pile in 1799 he started the journey to today's widespread electrochemical batteries. The pile, which was a stack of silver and zinc discs separated by pieces of brine-soaked fabric, was crude but when its ends were connected via metal wire, it produced a small electric current. In the years following the pile's invention, the battery was improved again and again, and now it is a fundamental source of portable power many of us couldn't live without.



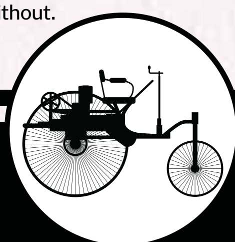
EVOLUTION OF…

24. Engine

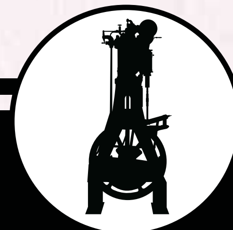
1712

From the 1712 Newcomen steam engine through to Karl Benz's two-stroke petrol engine used in cars and on to today's hi-tech hydrogen varieties, there is no doubt that the engine is one of the most significant inventions ever. Its usefulness has essentially been unrivalled for over 300 years as a motive force and, looking to the future, it seems to have plenty of life left in it. We pick out some of the key developments in its evolution now…

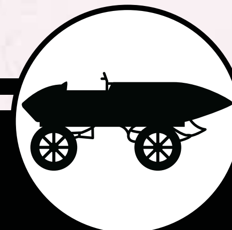
Steam engine
Steam engines date back to the first century CE, but it wasn't until Thomas Newcomen's engine in 1712 that they became useful machines.



Petrol engine
Karl Benz's invention of a reliable two-stroke petrol engine marked the end of the steam engine and led to the proliferation of the motor car.



Diesel engine
While the petrol engine was more momentous, Rudolf Diesel's creation of the diesel equivalent was just as useful and more eco-friendly too.



Electric engine
When Camille Jenatzy built an electric car in 1899, his electric engine was openly mocked. The car went on to break the land speed record.

1712

25. Electricity

1752

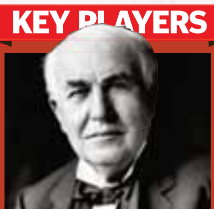
Okay, so this isn't an invention but rather a discovery. It is still, however, so momentous that it deserves a mention. While scientists had been fascinated with lightning and electricity for thousands of years – indeed, great philosopher Thales of Miletus undertook numerous experiments into the nature of static electricity in 600 BCE – it wasn't until Benjamin Franklin studied the phenomenon in 1752 that the two were reconciled and its true power realised. Following Franklin's work, electricity was harnessed in increasingly diverse ways, with Michael Faraday using it to lay down the foundations for the electric motor.

29. Photography

1826

For centuries the only way to record a person or place was with paint, which was a time-consuming and expensive process. That all began to change in 1826 when Joseph Nicéphore Niépce – a French inventor from Chalon-sur-Saône – produced the first permanent photographic image by covering a pewter plate with bitumen. Niépce continued to experiment and, after replacing the bitumen with silver, produced one of today's earliest surviving photographs.

KEY PLAYERS



Thomas Edison

1847-1931

Probably the greatest American inventor ever, Edison was responsible for the first commercially successful light bulb, the phonograph, the electric vote recorder, the railway turntable and the kinetographic camera (one of the first motion-picture cameras), to name a few.

28. Canned food

1810

While canned food may get a bad rap today for not being 'fresh', it has been and remains a critical source of nourishment in many parts of the world. Indeed, canned food has many benefits, including acting as a preservative and providing a protective container for transportation. As such, when it was invented in the early-19th century, it radically transformed what the average person ate.

30. Light bulb

1835

Many years before Thomas Edison and Joseph Swan introduced their own light bulbs to the world, a Scotsman called James Bowman Lindsay demonstrated a constant electric light at a public meeting in Dundee. Reportedly, Lindsay's light was so powerful and stable – for 1835 at least – that he could read his book from a distance of 0.4 metres (1.5 feet). Lindsay had invented the world's first electric light bulb, however he neither patented the device nor sold it, instead moving on to wireless telegraphy. Regardless, Lindsay's innovation was continuously honed in the following decades and, after Edison married a stable electric generator to this revolutionary light-giving device, the stage was set for its widespread adoption. Today, it's hard to imagine a world without electric light bulbs and they're often voted one of the greatest inventions of all time in polls.

Hydrogen engine
Still in development today, the hydrogen engine could potentially render petrol-based engines obsolete, helping to cut levels of pollution.

31. Plastic

1856

In 1856 British scientist Alexander Parkes created the first man-made plastic from cellulose treated with nitric acid. Trademarked as Parkesine, Parkes' invention soon won him a bronze medal at the 1862 Industrial Exhibition in London and, as a result, he decided to ramp up production of the new material. Unfortunately, after beginning mass production of the plastic, a mixture of demand and high costs saw his company fail and, by 1868, Parkesine was no longer made.

Patent pending

While today the patent is best known for the ongoing corporate patent wars between companies like Apple and Samsung, originally the patent was an incredibly simple thing. When someone made an invention, their labour was protected from theft so they could enjoy any material benefits that derived from it.

The first reference of a patent system dates from 500 BCE, where in the Ancient Greek city of Sybaris 'encouragement was held out to all who should discover any new refinement in luxury, the profits arising from which were secured to the inventor by patent for the space of a year.' The history of modern patent law, however, is now widely agreed to have started in Italy in 1474, when a Venetian statute decreed that all completed inventions had to be made public to obtain any ownership rights.

From this point on patent systems evolved throughout the world, allowing civilians to freely create new inventions and advance society. Today, anyone can request a patent for an invention provided it is original and does not infringe on any previously filed patents.

1876

32. Telephone

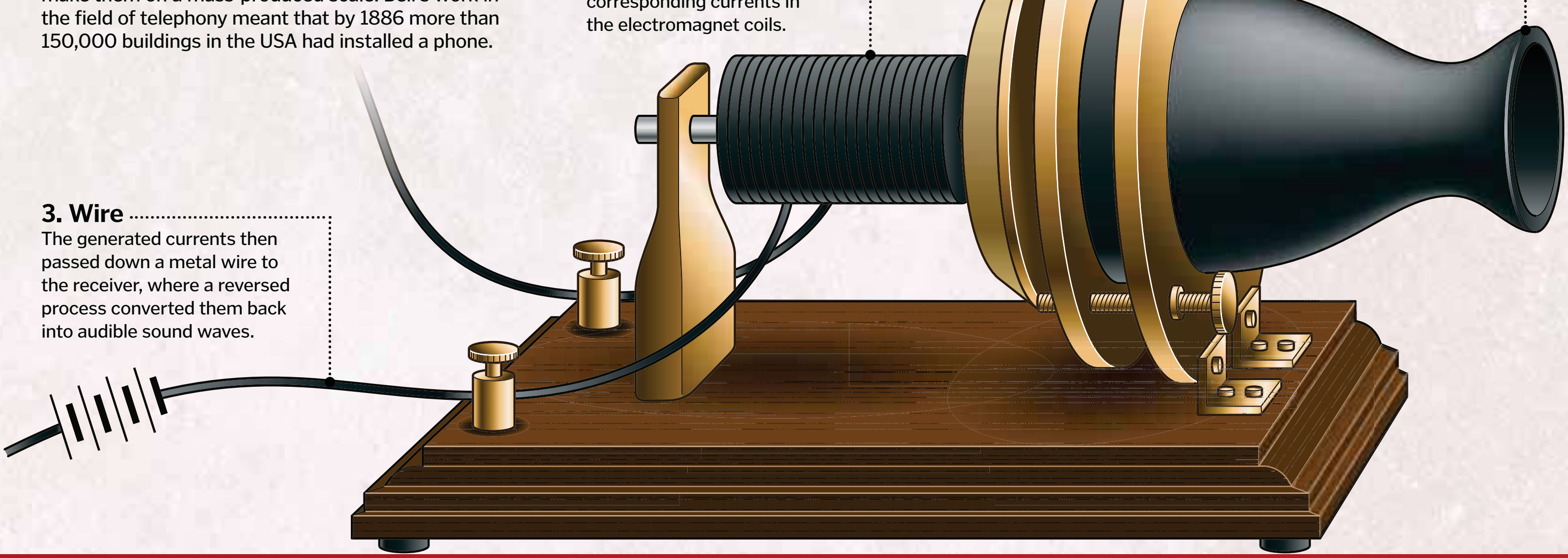
1876

While not the inventor of the world's first telephone (largely attributed to Antonio Meucci in 1849), Alexander Graham Bell achieved so much in its overall development – including taking out a patent for his own device in 1876 – that he is generally now credited as its inventor. Indeed, along with his assistant, Thomas Watson, Bell built a phone that enabled him to make the first ever call, saying, 'Mr Watson, come here, I want to see you.' He demonstrated its capabilities to many important societies and people – even to the US president – and eventually set up the Bell Telephone Company to make them on a mass-produced scale. Bell's work in the field of telephony meant that by 1886 more than 150,000 buildings in the USA had installed a phone.

"Bell built a phone that enabled him to make the first ever call, saying, 'Mr Watson, come here, I want to see you'"

1. Mouthpiece
A funnel-shaped mouthpiece received spoken sound waves and directed them against an internal membrane.

2. Coils
As the membrane vibrated, the attached soft-iron armature induced corresponding currents in the electromagnet coils.



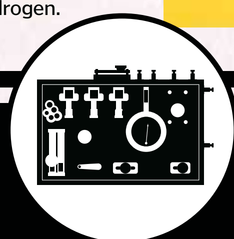
3. Wire
The generated currents then passed down a metal wire to the receiver, where a reversed process converted them back into audible sound waves.

33. Phonograph
1877
The first device to be capable of recording and replaying sound, Thomas Edison's 1877 phonograph laid down the foundations for today's music industry, being quickly followed by the gramophone and, later, the turntable. Prior to this no audible moments could ever be captured or replayed. Today, radios and MP3 players allow us to listen to our favourite tunes all day long.

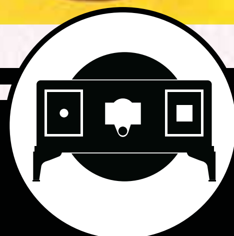
34. Car
1882
Taking over from steam- and horse-powered travel at the end of the Industrial Revolution, where would we be today without the car? First made in its current form in 1886 by German engineer Karl Benz, there are now more than 1 billion worldwide, and that number is set to keep growing. Newer designs are looking to solve the problem of pollution by using alternative energy sources, such as hydrogen.

EVOLUTION OF...

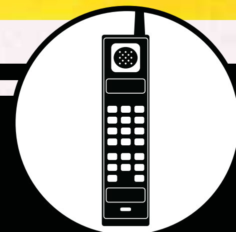
36. Wireless communications
1891
Responsible for eventually giving us the television, mobile phone, radio, radar, satellite navigation and even wireless internet access, Nikola Tesla's work in 1891 creating a wireless communications network was surely one of the most inventive spells of his career. Since Tesla's network, wireless communications have gone from strength to strength, as the following devices show...



Radio
Sir Oliver Lodge sent the first transmission signal in 1894 – a year before Marconi, who was later awarded the wireless telegraph patent.



Television
Scottish inventor John Logie Baird demonstrates the world's first moving image on his 'televisor' device – a mechanical precursor to the TV.

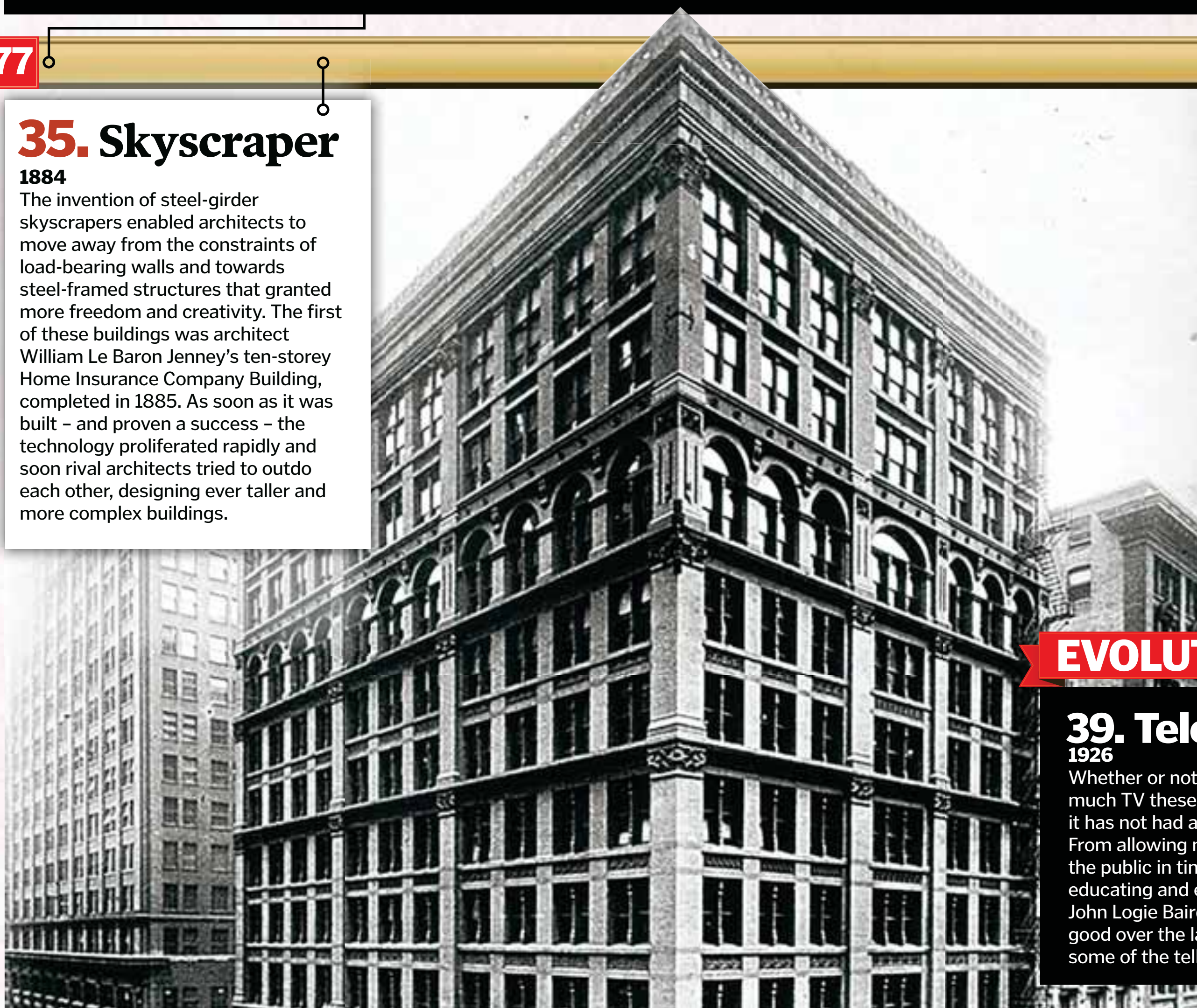


Mobile phone
The first handheld mobile phone is demonstrated by two employees at Motorola. It weighs in at a rather hefty one kilogram (2.2 pounds).

Wi-Fi
While wireless internet existed in academic facilities, it wasn't until 1997 that standards were laid down for its widespread adoption.

1877

35. Skyscraper
1884
The invention of steel-girder skyscrapers enabled architects to move away from the constraints of load-bearing walls and towards steel-framed structures that granted more freedom and creativity. The first of these buildings was architect William Le Baron Jenney's ten-storey Home Insurance Company Building, completed in 1885. As soon as it was built – and proven a success – the technology proliferated rapidly and soon rival architects tried to outdo each other, designing ever taller and more complex buildings.



KEY PLAYERS

Benjamin Franklin
1706-1790
Famed for his experiments with electricity, Franklin was also quite an inventor, designing the Franklin stove, bifocal glasses, a flexible urinary catheter, the lightning rod and the glass armonica. He was considered one of the most important figures in the American Enlightenment.

EVOLUTION OF...

39. Television
1926
Whether or not you think we watch too much TV these days, it's hard to argue that it has not had a beneficial effect since 1926. From allowing national leaders to address the public in times of emergency to educating and entertaining the masses, John Logie Baird's invention has done much good over the last 87 years. Check out some of the telly's milestones now...

Accidents of invention

Penicillin
When Scottish scientist Alexander Fleming decided to take a month-long holiday in August 1928 to see his family, he left his London lab in a bit of a mess – including abandoning numerous Petri dishes of staphylococci. Upon his return he noticed that on one of the dishes a mould had grown that had killed any nearby staphylococci. After regrowing the mould in a pure culture he found that it destroyed a number of disease-causing bacteria. As a result, penicillin – one of the most successful antibiotics to this day – was born.

Coca-Cola
Probably the most commercially successful accident of all time, the soft drink Coca-Cola was not the corporate juggernaut it is today when invented but rather a medicinal cure for headaches… Or so the pharmacist John Pemberton from Atlanta, GA, believed when he began selling his secret mixture in 1886 for five cents a pop. 50 years later and Coca-Cola had become a national symbol of America due to its phenomenal success; in fact, in 2011 it was voted the most well-known brand in the world.

Vulcanised rubber
19th-century rubber king Charles Goodyear spent years trying to make a rubber that was easy to manufacture yet resistant to heat and cold. After many failed attempts one day he just happened to drop a rubber mixture on a hot stove. Believing it ruined, Goodyear retrieved the charred rubber and, when holding it, discovered it was hardened but still flexible. After a little experimentation, he quickly realised that by heating a mixture of rubber and sulphur he could create his desired vulcanised rubber – today used in tyres, shoes and more.

Microwave oven
Percy LeBaron Spencer was not even trying to invent anything when he accidentally conceived of the microwave oven. Working at Raytheon Company during the 1940s, by chance, Spencer noticed one day while walking past a radar tube that a chocolate bar that was in his pocket had melted. After testing the effects with other foods – including popcorn – Spencer realised that magnetrons could be used to cook food, thus devising the concept of the microwave oven.

38. Refrigerator

1922
One of the most useful day-to-day inventions of the 20th century, the refrigerator allows our food to be stored over long periods, reducing the growth of bacteria dramatically. It was invented originally in 1922 when two students at the Royal Institute of Technology in Stockholm, Sweden, created a gas-absorption chilling cabinet. Unlike modern fridges though this device did not use an electrically driven compressor to maintain internal temperature, but instead an ingenious system of state-changing gases. After realising its potential the inventors put the refrigerator on sale. Unfortunately, it never really caught on, leaving the later electric fridge to make the jump to mass-market success.

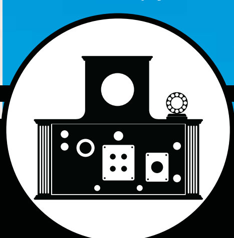
1928

37. Aeroplane

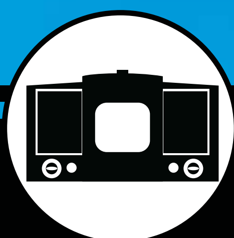
1903
The Wright Brothers' Wright Flyer in 1903 kick-started the age of aviation, with rotor and then jet-powered craft transforming travel in the 20th century. From military fighter jets through to supersized passenger aircraft, air travel means we can reach each other much faster than ever before. To think that within just 73 years we went from the primitive Wright Flyer, which only travelled a distance of 260 metres (852 feet) to the Aérospatiale-BAC Concorde supersonic passenger jet, capable of cruising comfortably at 2,172 kilometres (1,350 miles) per hour for thousands of miles is simply mind-blowing.

40. Penicillin

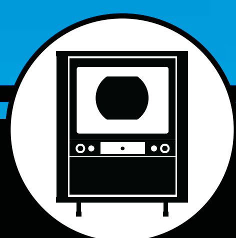
1928
Discovering penicillin might have been a happy accident, but nevertheless Alexander Fleming's find was a pivotal moment in modern medicine, with the bacteria-fighting antibiotic quickly rolled out. Fleming would go on to win a Nobel prize in 1945 for his work. Today, penicillin is available commercially for treating a wide range of infections.



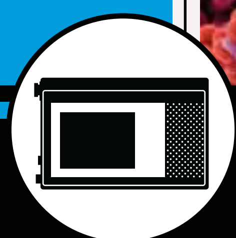
Farnsworth
American inventor Philo Farnsworth makes the first all-electronic TV that is commercially viable, receiving a patent for his device in 1930.



Mass-market
RCA starts the era of mass-produced TVs with the release of the RCA 630TS in 1946. By 1950 the number of TVs has climbed to the millions.

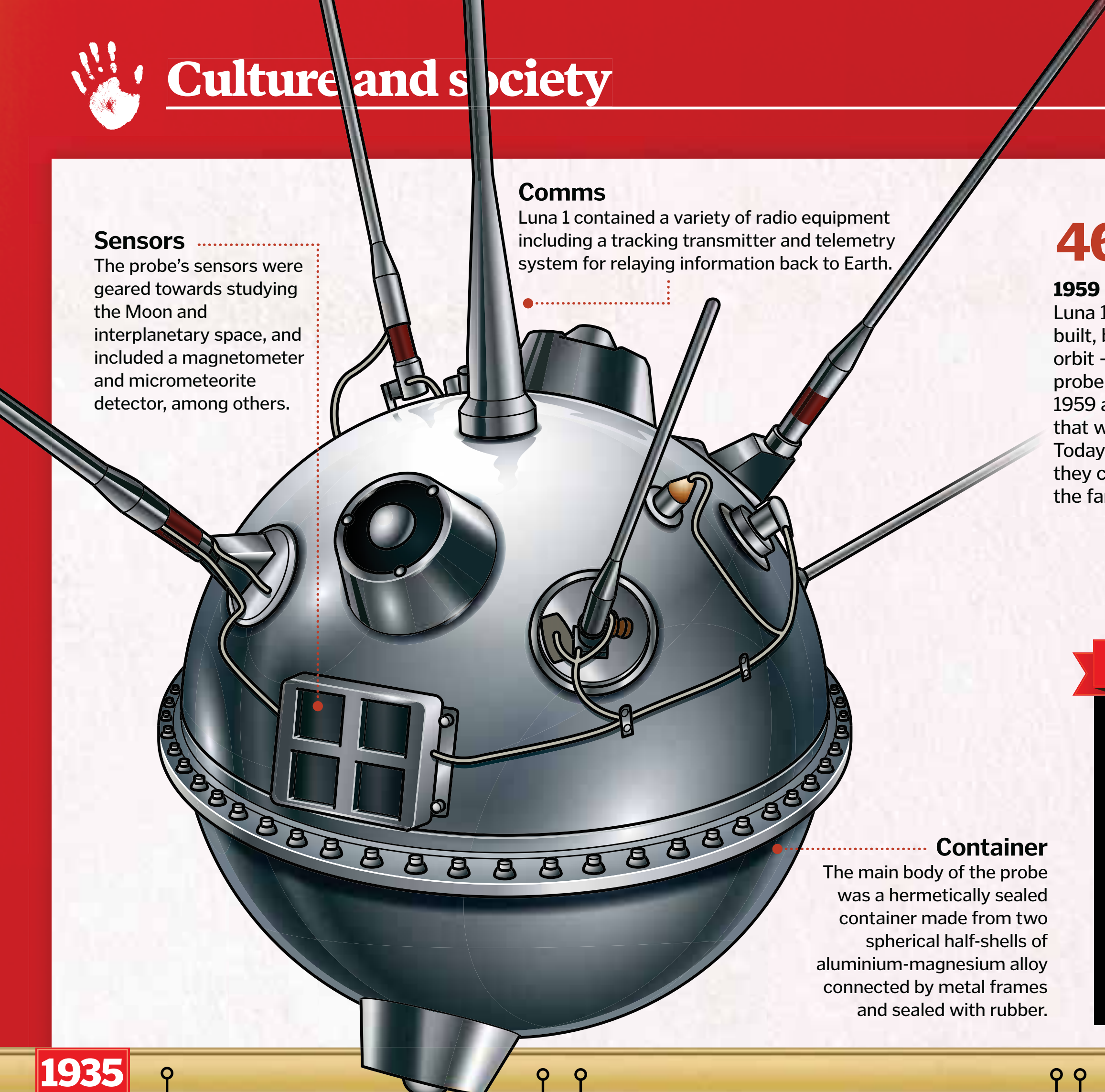


Westinghouse colour
Introducing colour, the Westinghouse H840CK15 goes on sale for $1,295. With only 500 built, it will be 15 years before colour TV goes mainstream.



Casio TV-10
The first LCD TV to be sold commercially is the TV-10, which while only offering standard low resolutions kick-starts the flat-panel TV market.

LED backlight
The first LED TV – a flat-panel screen that uses LEDs to illuminate the LCD panel instead of cathode lighting tubes – is produced by Sony.



46. Space probe

1959

Luna 1 (pictured left) wasn't the first space probe to be built, but it was the first to successfully leave a geocentric orbit – the key criterion for classifying one today. The probe was built as part of the USSR's Luna programme in 1959 and paved the way for a series of other Luna probes that would explore the Moon in unprecedented detail. Today, we have created space probes that are so advanced they can image alien worlds in high definition and travel to the farthest reaches of our Solar System and beyond.

EVOLUTION OF...

49. Personal computer

1973

Be it a desktop, laptop, tablet or smartphone, the average person owns at least one personal computational device, for performing a variety of tasks. Whether it's for writing letters, receiving mail, checking the weather, making phone calls, shopping, playing games, calculating sums or booking a holiday, computers can handle it – and a whole lot more. Indeed, the empowering qualities of the PC are massive and it is easy to see why many argue it's the most important device on Earth.

1935

41. Radar

1935

It's funny to think that the radar, one of today's most useful inventions, was born out of a British-funded 'death ray' project during the runup to WWII. But that is exactly what the British government asked Scottish scientist Robert Watson-Watt to build: a machine to 'destroy personnel'. Watson-Watt realised the death ray was impossible to build, but did suggest that radio waves could be used to monitor distant objects.

"The death ray was impossible, but radio waves could monitor distant objects"

43. Microwave oven

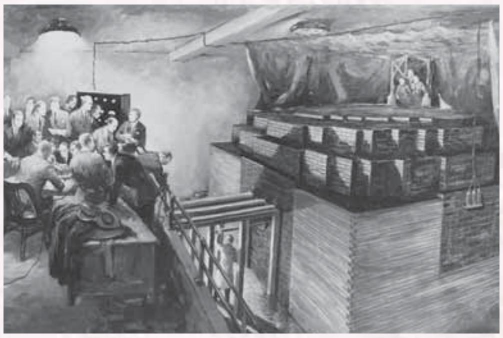
1947

The microwave oven was created by chance (see 'Accidents of invention'), but despite its serendipitous origins, the first commercial microwave was sold in 1947, with the Raytheon Company releasing its Radarange unit. The Radarange was 1.8 metres (six feet) tall, weighed 340 kilograms (750 pounds) and cost $5,000 – over £33,800 ($51,000) by modern standards! Today, the microwave is a staple feature in most kitchens as a speedy means to cook our food.

42. Nuclear reactor

1942

The world's first nuclear reactor was the Chicago Pile-1 (pictured), which was constructed as part of the USA's Manhattan Project in WWII. Built under the western stands of Stagg Field at the University of Chicago, the reactor was fairly crude, comprising a pile of uranium pellets and graphite blocks. Regardless of its rustic build, the reactor initiated the first self-sustaining nuclear chain reaction on 2 December 1942 and kick-started the age of nuclear power.



45. Credit card

1958

Almost nobody goes anywhere today without some form of debit or credit card, but not so long ago all we had was physical currency. However in 1958 the Bank of America launched its BankAmericard credit card in Fresno, CA. Despite the credit card system being abused by fraudsters in its first year, the BankAmericard was eventually a success and, in 1976, changed its name to Visa. Today, Visa cards are one of the most widely used payment cards on the planet.

44. Medical imaging

1953

Medical imaging techniques such as ultrasonography – invented in 1953 at the University Hospital in Lund, Sweden – have revolutionised the field of medicine, granting doctors an unprecedented window into their patients' bodies. Today, ultrasound scans use probes with acoustic transducers to transmit pulses into the body to check on babies in the womb and more.

47. Internet

1960s

Another invention to which no firm date nor name can be ascribed, the internet nonetheless remains an absolute necessity for a top inventions list. With origins buried in US military facilities during the Sixties as a way to deliver fault-tolerant communication between individual computer networks, the internet soon grew in scale, with the development of increasingly large and complex networks. By the early-Eighties an identifiable backbone of the internet had emerged with its potential being realised, both commercially and academically. As a result, companies and institutions started linking their own networks and – along with the birth of the World Wide Web – a new era of online communication, business and entertainment had dawned.

KEY PLAYERS

Tim Berners-Lee

1955 – present

As the main brain behind the World Wide Web, Berners-Lee revolutionised communications. While the internet existed pre-1989, it was only used by a select few; the World Wide Web brought it to the masses.

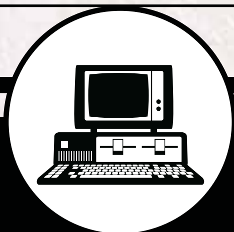
48. Satellite

1962

Military and governmental satellites had existed for over half a decade when the Telstar satellite was launched into space on top of a Thor-Delta rocket on 10 July 1962. But that didn't stop it from becoming one of the most important satellites of all time. This was because the Telstar was the first commercially funded initiative to develop satellite communications over Europe – a technological advance that would lead on to today's widespread satellite-reliant communications and entertainment. Indeed, Telstar would go on to successfully transmit the world's first transatlantic television pictures, telephone calls and fax images. Telstar 1 is still in orbit around Earth but is no longer functional.

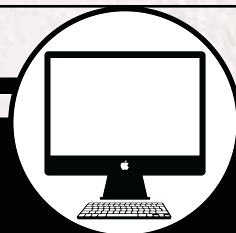
Xerox PARC
This early personal computer sets the benchmark for their design, incorporating a monitor, keyboard, mouse and graphical user interface (GUI).

Commodore PET 2001
One of the first mass-market PCs, the PET 2001 featured a 1MHz CPU and up to 96KB of memory. It came in a one-piece form-factor, unlike the PARC.



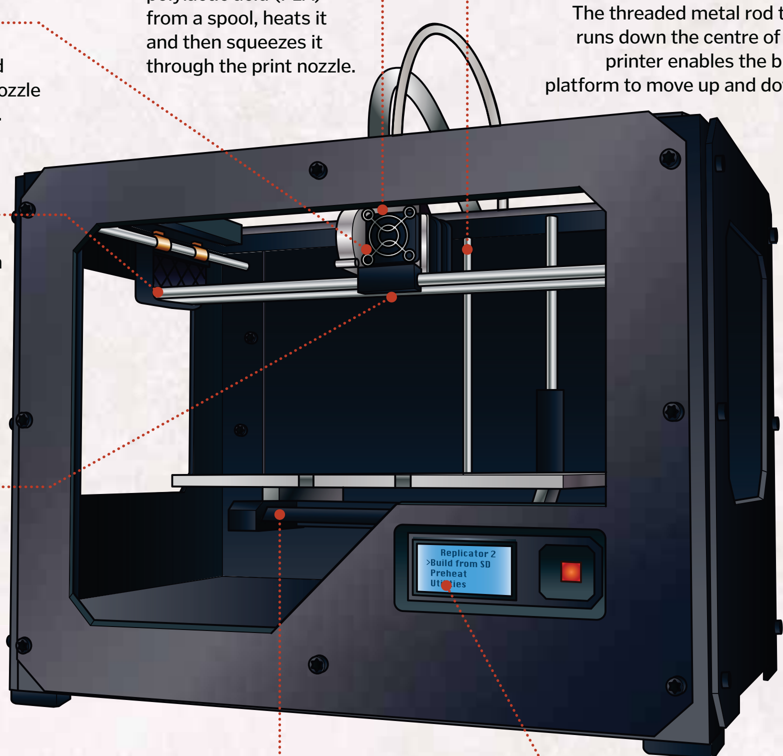
IBM PC 5150
Tech giant IBM's first mass-produced PC sold fantastically well and went on to become a business industry standard. The IBM 5150 had a 4.77MHz CPU.

Power Mac 9500
One of the first of a new wave of hi-spec PCs, the Mac 9500 helped popularise the separate desktop tower case and now-widespread PCI standard connector.



iMac
The iMac helped push the now popular all-in-one unibody design standard, with high-resolution LED screens and super-fast, multi-CPU PCs now the norm.

1984



Extruder
The extruder draws in polylactic acid (PLA) from a spool, heats it and then squeezes it through the print nozzle.

Z-axis rod
The threaded metal rod that runs down the centre of the printer enables the build platform to move up and down.

Cooling fan
An active cooling fan blows on the liquefied PLA as it leaves the nozzle so it solidifies quickly.

Gantry
The extruder is secured to a gantry in the top of the printer. The extruder runs on the gantry to allow for each layer's precise positioning.

Print nozzle
The opening on the end of the extruder from which the heated PLA filament emerges to be deposited onto the build plate.

Build platform
The support for the build plate, where the PLA is deposited. The build plate can be level adjusted to suit a range of printing projects.

Controller
Instruction sets for an object's cross-sectional layers are fed through the printer's motherboard and into the extruder controller.

50. 3D printer

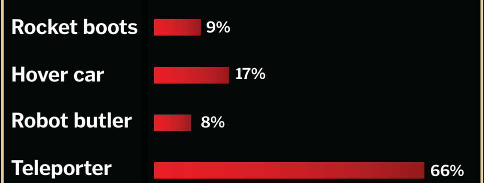
1984

And so we come to the last of our 50 inventions and, in some respects, we have come full circle, as we end with an invention that is arguably the closest thing we currently have to a machine that can create more machines! And that is the 3D printer, a device born in the mid-Eighties that – fed with CAD designs – can build objects, sculptures, gears, component parts, organs, artificial limbs, toys and much more through an ingenious layering of liquid plastics. The complexity of some of the things modern 3D printers are capable of making is truly astounding and, with work already underway to upscale both their commercial availability and their potential applications – such as a project to make a printer capable of printing entire houses – this particular invention has a very bright future ahead of it.

READERS' FANTASY POLL

Which of these inventions do you wish existed?

For fun, we picked four fantasy inventions and asked which one **How It Works** readers would most like to see. Here are the results…



WHAT MAKES US HUMAN?

Humanity's best ideas

From storytelling to democracy, discover the concepts that are key to our society

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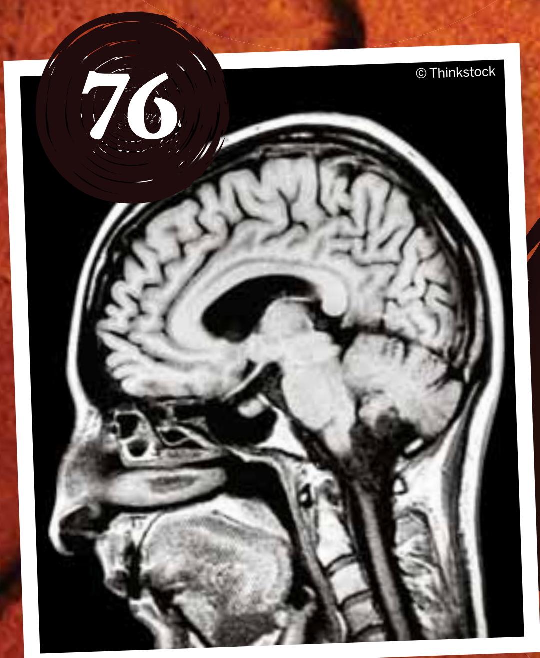

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The human brain

What makes our minds the most complex objects in the known universe?

What you're made of

The elements in our bodies were forged inside ancient stars

© Pixabay

86

The importance of fear

How the primal response of fight or flight is key to our survival

Your first year

Many milestones occur during this crucial stage of human development

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90

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96

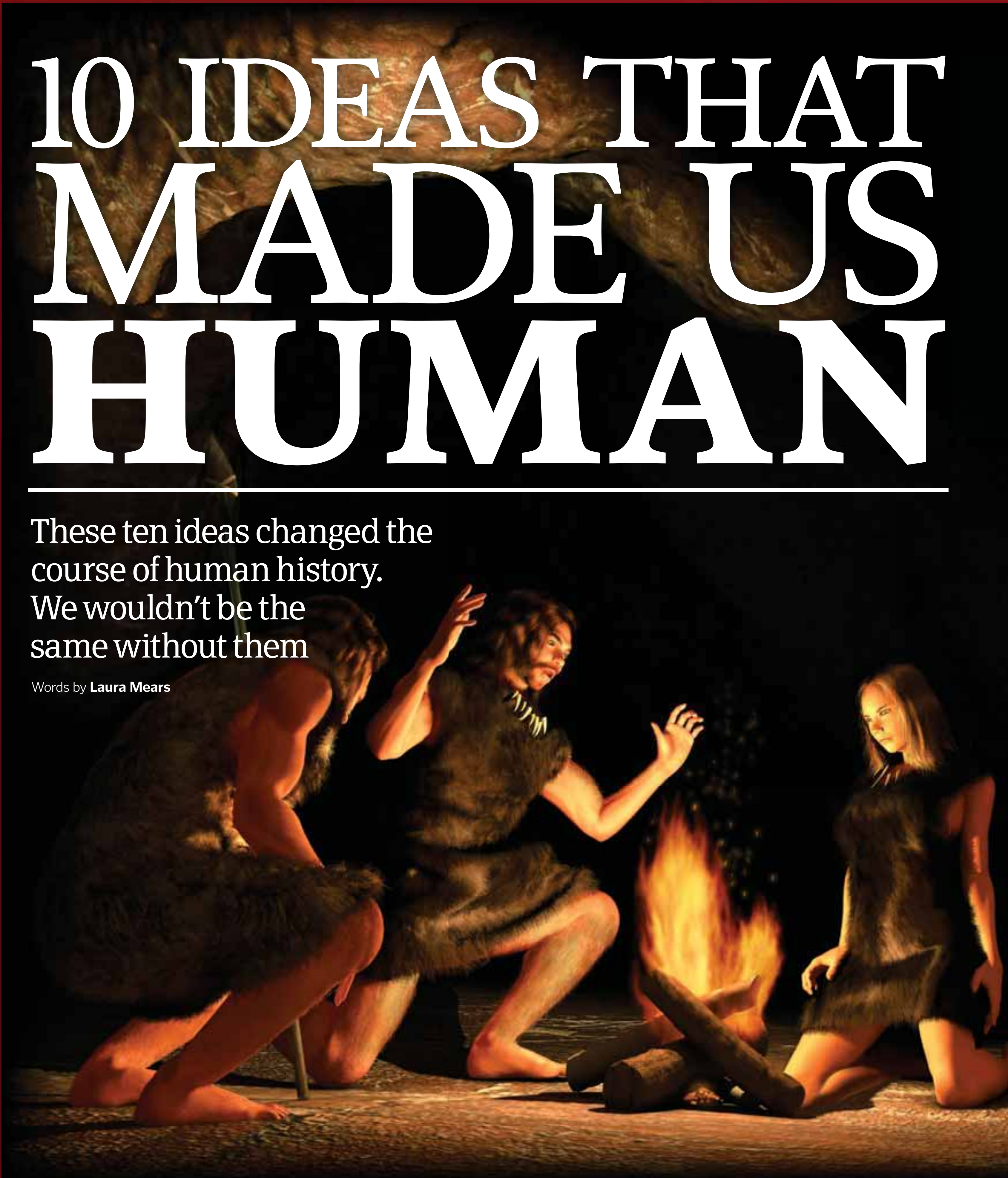
The power of imagination

Our unique ability to take what we know and dream up something completely new

10 IDEAS THAT MADE US HUMAN

These ten ideas changed the course of human history. We wouldn't be the same without them

Words by **Laura Mears**



Storytelling

Storytelling is perhaps the most important idea in the history of our species. The stories that we tell about our experiences, feelings and ideas are the glue that connects us together as communities. And they're the vehicle for sharing every other idea that makes us human. They help us to make sense of the past, and to prepare for the future.

Look back into our history and you'll find stories everywhere: painted on the walls of caves, etched into ancient stone tablets, passed down from one generation to the next as song and dance. But look across the rest of the animal kingdom, and you won't see stories anywhere. Our ability to tell tales depends on a unique feature of human communication. We think syntactically, something that no other animal seems to be able to do. This means that we are able to break ideas apart into smaller pieces and fit them back together to make something new. Our closest living relatives, chimpanzees, can learn sign language, but they can't tell tales. The longest sentence a chimpanzee called Nim managed was: "Give orange me give eat orange me eat orange give me eat orange give me you."

Our ability to tell stories sets us apart from other species, and it's one of the secrets to our success. Stories have enabled us to pass knowledge and culture from person to person, from place to place, and from generation to generation. Together, we have built complex narratives over thousands of years, and these stories have shaped the whole of human history.

DID YOU KNOW?

Good storytellers in forager cultures often enjoy higher social status within their tribes

Trading with money

Our species is able to collaborate on a scale unseen anywhere else in nature, and that's partly down to money. This idea enables us to exchange goods and services with strangers using a trusted system of tokens.

It started out with the exchange of crops and animals, a system knows as 'commodity money'. Livestock and bundles of wheat were valuable. People were willing to trade for them because they knew they could trade them on in the future. The trouble was, perishable commodities were hard to move and store, and they lost their value if they died or went off. People needed a way to store value for the future so that they could trade for the things they needed, when they needed them.

Metal was a good alternative. It was easy to carry, you could split it into pieces, and it was always in demand. As people got used to trading metal, trust started to build. Soon, instead of exchanging valuable coins and bars, people were happy to swap cheap metal tokens and paper receipts. Until relatively recently, it was possible to exchange this 'representative money' for gold at the bank. In the UK today, 96 per cent of currency is electronic, and there is something known as 'fiat money' – there's no gold in the bank to back it up. With collective trust in this system of exchange, the economy can now continue to grow without us having to go out and mine more metal.

Making music

No one knows quite how old the idea of music is, but we've had the tools to make it for the entire history of our species. Our bodies are biological instruments. Our vocal cords work a bit like guitar strings, except that they're embedded in a gel. This means that, instead of playing one note at a time, we play several all at once. What's more, the human larynx, which contains the vocal cords, is lower down in our throats than it is in other apes. This extends the distance between the vocal cords and the mouth, turning our heads and chests into resonance chambers.

Hard evidence of human music dates back tens of thousands of years, but it's likely that we've been sharing songs for much longer. The earliest instruments ever recovered are 40,000-year-old bone pipes with finger holes and v-shaped mouth pieces. These flutes are so complicated that it's likely that people had been experimenting with simpler instruments for some time. Unfortunately, we're unlikely to find them because they were probably made from degradable materials like skins, reeds, wood and gourds. Though we don't know exactly when music began, the impact it's had on our culture is clear. It has become a form of social grooming, bringing people together to share stories, emotions and ideas.

"Music can evoke a range of emotions without any words"

DID YOU KNOW?

Humans aren't the only animals to make pop music; trend-setting humpback whales also spread new songs

Cooking food

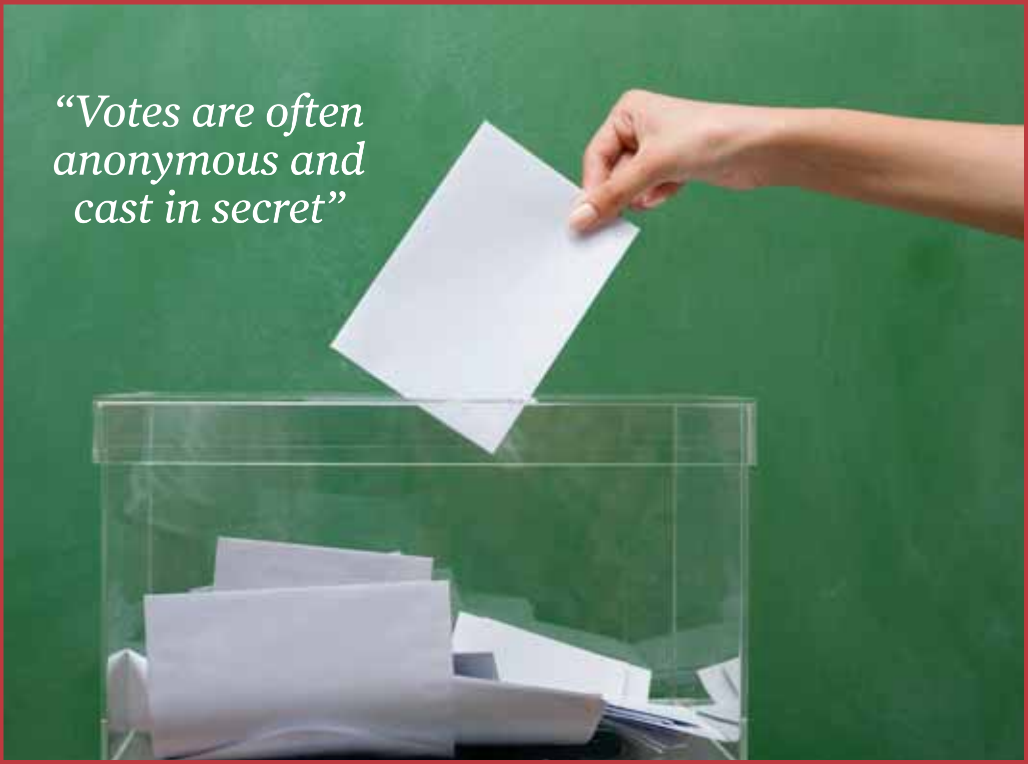
The idea to combine food and fire changed the course of human history, and it dates back hundreds of thousands of years. Deep within Wonderwerk Cave in South Africa, away from natural fires, archaeologists have found million-year-old ash. The charred remains of grass, leaves and bones were left there by Homo erectus. Fast forward 700,000 years, and other hominid species had started cooking too. In Qesem Cave in Israel, there is an ash-filled fire pit littered with fragments of bone. These early pioneers changed our relationship with food forever. Cooking does two amazing things: it makes food easier to digest, which increases the amount of nutrition we can extract from it, and it kills pathogens, making us less likely to get sick. Cooking expanded our culinary options to include tough and toxic foods, like potatoes and cassava, and it helped us to preserve food for the future. Not only did this fuel the growth of our brains and improve our chances of survival, but it also gave us more time to explore and invent. And, as our cooking skills improved, food started to take on another role. No longer purely fuel, food became a source of joy and pleasure. The hearth became a social centre, and food a way to share, bond and celebrate.

"The hearth is still the heart of the home and cooking brings people together"

The will of the majority

Democracy literally means people (demos) rule (kratos). It's an idea for a system of government where citizens get a say in who their leaders are, and how they run the country. Unlike other forms of rule, including aristocracy, where the wealthy make the decisions, or monarchy and oligarchy, where one or a few people lead, democracy is based on the will of the majority.

There are two types of democracy, direct and representative, and they work in slightly different ways. Direct democracy allows each citizen to vote on every decision. It has roots in Ancient Greece in the fifth century BCE, where adult Athenian males were able to attend weekly assemblies on a hill called the Pnyx, raising their hands to cast votes on the issues of the day. But, although this type of democracy gave citizens direct control of their community, it wasn't easy to scale. Representative democracy, which emerged in 12th-century Italy, is an alternative system that many countries now use instead. Rather than vote on every issue, citizens elect representatives to vote on their behalf. This helps to make sure that people are not subjected to power that they don't agree with, without the need to turn out to vote every day.



"Votes are often anonymous and cast in secret"

Division of labour

We can't all be good at everything, but thanks to division of labour, we don't have to be. This economic idea describes how we break tasks down into smaller parts so that individuals can become specialised.

We all have different occupations. Some people run the country, some grow food, others care for the sick, invent new technologies, or clean the streets. Within occupations, we have process specialisation. In a garment factory for example, different people cut the fabric and sew the seams.

We also divide labour by location, such as city and country, locating our businesses next to the materials and expertise that they require.

This idea became more important as our societies grew, and as manufacturing became more industrialised. It helps to increase efficiency and quality, reduce costs and save time. This frees us up to be more inventive.

Keeping time

The modern world would grind to a halt without accurate clocks. They coordinate everything, from getting us up in time for work to keeping GPS satellites in sync. But even though we're born with biological clocks built-in, it took millennia for our species to learn to tell the time.

Experiments with time began with sundials, candles, incense, water and basic mechanical systems, but it wasn't until pendulum clocks started swinging in the 17th century that we really got to grips with time. These new devices helped ships to determine longitude, making sure they did not drift off-course on long voyages.

Later that century, the invention of the spiral-hairspring made clock technology portable. Quartz clocks followed at the start of the 20th century, and in the 1950s, scientists built the first accurate atomic clock.

This is the technology that keeps us all in time today.

DID YOU KNOW?

We have sent hundreds of people into space, but only four have journeyed to the deepest part of the ocean

Exploring the world

Humans are born explorers. Between 60,000 and 70,000 years ago, our species left Africa in search of new horizons, taking with them sophisticated tools and dangerous weapons. They travelled to Asia, following the coast of the Indian Ocean all the way to Australia. Around 40,000 years ago, they moved north into Europe. Then, 15,000 years ago, they made the crossing to the Americas. This taste for adventure drove the development of new transport technologies: the wheel 5,000 years ago, domestic horses and donkeys 4,000 years ago, and compasses 3,000 years ago. Long-distance seafaring became possible in the 1500s; canals and trains came along in the 1800s; and in the 1900s, we invented cars, planes and spacecraft. The urge to explore has taken our species around the globe and beyond.

The scientific method

The scientific method is a way of thinking that helps us to investigate the world around us. It begins with an observation, followed by a question, a hypothesis and then a prediction. Finally, experiments test whether the prediction is correct. An example of the scientific method in action is Gregor Mendel's experiments on peas. He observed that some pea plants had purple flowers and others had white flowers, and he asked what would happen if they interbred. His hypothesis was that inheritance worked by blending. This led to the prediction that the next generation of flowers should be light purple. To test this prediction, Mendel cross pollinated purple and white plants, but unexpectedly, all the flowers came out purple. Using this new information, he designed new questions and new experiments, eventually leading to his theory of genetic dominance. This way of conducting science has revolutionised the way we learn about the world.

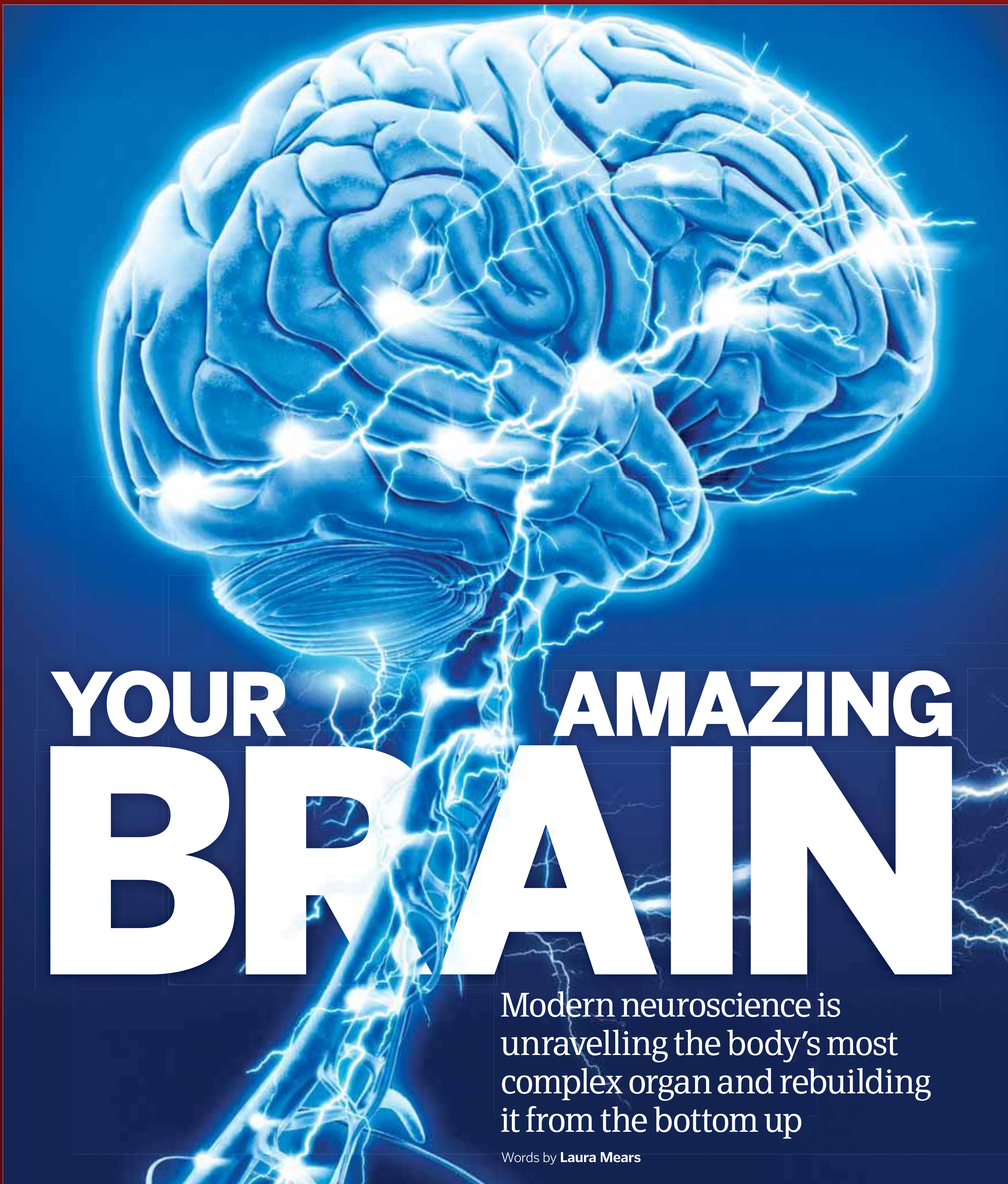
DID YOU KNOW?

The scientific method is based on empirical evidence, data gathered from what we observe or experience

The germ theory

By the Middle Ages, doctors had worked out that alcohol was an antiseptic, and they knew that quarantine could stop disease, but they didn't know why. They thought that illnesses spread by miasma (bad smells) and contagion (direct contact).

They had seen microbes down the microscope, but they hadn't made the link between germs and disease. The big breakthrough came when Louis Pasteur published his 'germ theory' in 1864. His work, and the work of another scientist, Robert Koch, changed our understanding of infection forever. We finally knew our enemy, and could set about making vaccines and antibiotics to fight the diseases that had plagued our species for centuries. Life expectancy at birth in England and Wales has doubled since the 1800s, and that is in no small part down to modern medicine.



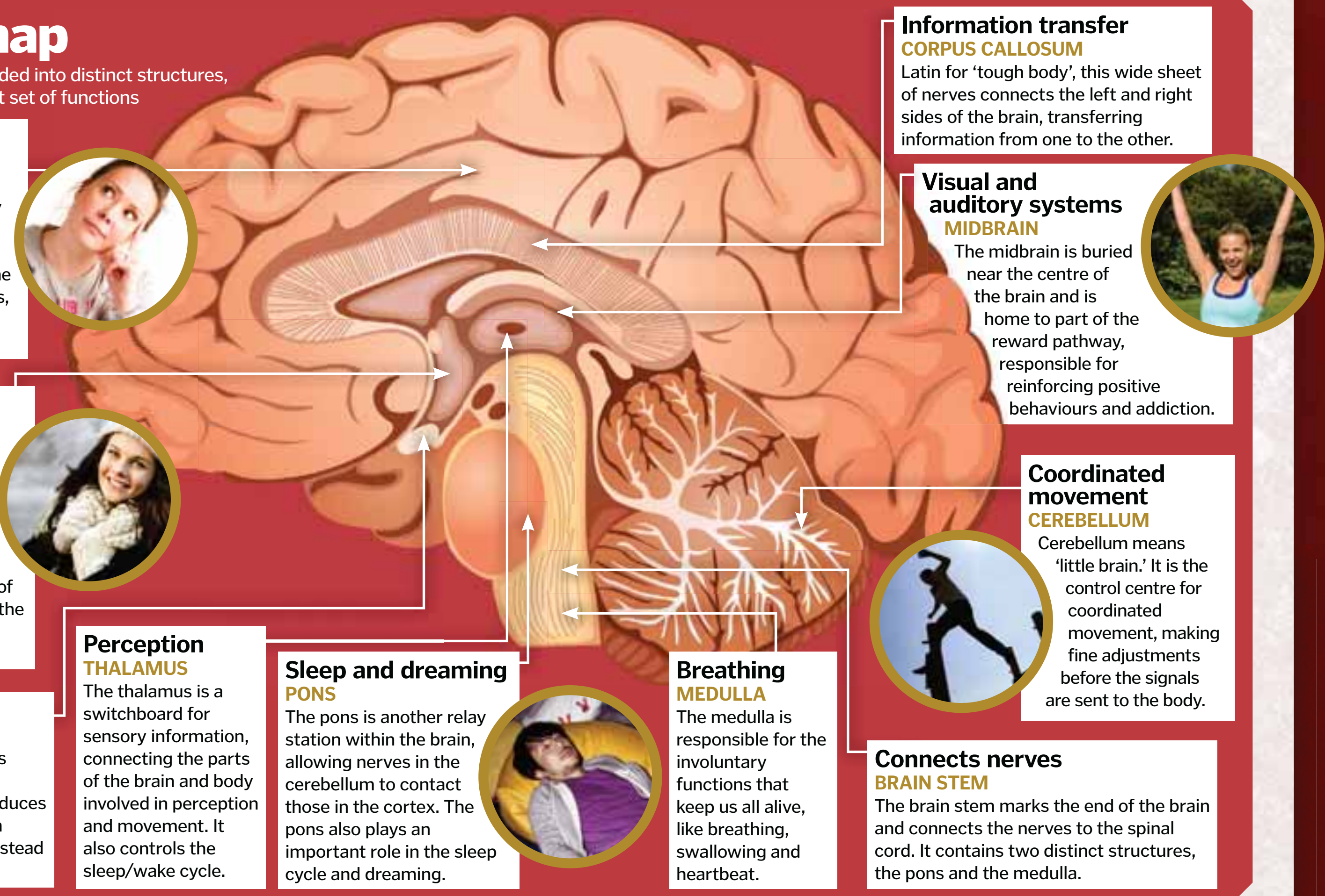
YOUR AMAZING BRAIN

Modern neuroscience is unravelling the body's most complex organ and rebuilding it from the bottom up

Words by **Laura Mears**

Brain map

The brain can be divided into distinct structures, each with a specialist set of functions



Memory
CEREBRUM
The cerebral cortex makes up the majority of the human brain. It is divided into four lobes, which handle the most complex of tasks, including planning, memory and vision.

Temperature and hydration
HYPOTHALAMUS
The hypothalamus is responsible for maintaining equilibrium within the body. It monitors and adjusts a variety of vital parameters, like the body's temperature and hydration.

Hormones
PITUITARY GLAND
This pea-sized gland is connected to the hypothalamus and produces hormones, passing on chemical messages instead of electrical impulses.

Perception
THALAMUS
The thalamus is a switchboard for sensory information, connecting the parts of the brain and body involved in perception and movement. It also controls the sleep/wake cycle.

Sleep and dreaming
PONS
The pons is another relay station within the brain, allowing nerves in the cerebellum to contact those in the cortex. The pons also plays an important role in the sleep cycle and dreaming.

Breathing
MEDULLA
The medulla is responsible for the involuntary functions that keep us all alive, like breathing, swallowing and heartbeat.

Information transfer
CORPUS CALLOSUM
Latin for 'tough body', this wide sheet of nerves connects the left and right sides of the brain, transferring information from one to the other.

Visual and auditory systems
MIDBRAIN
The midbrain is buried near the centre of the brain and is home to part of the reward pathway, responsible for reinforcing positive behaviours and addiction.

Coordinated movement
CEREBELLUM
Cerebellum means 'little brain.' It is the control centre for coordinated movement, making fine adjustments before the signals are sent to the body.

Connects nerves
BRAIN STEM
The brain stem marks the end of the brain and connects the nerves to the spinal cord. It contains two distinct structures, the pons and the medulla.

The human brain is the most complicated structure in the known universe. It has taken hundreds of millions of years of evolution to construct, and over the last seven million years, it has tripled in size. It weighs little more than a bag of sugar, but packed inside it are 86 billion neurons, linked together by over 100 trillion connections in a network more powerful than even the most advanced supercomputers ever built.

By far the largest part of the human brain is the forebrain, and like the brains of other mammals, it is covered in a thick layer of neurons known as the cerebral cortex. But in humans, this layer has been massively expanded. The human cerebral cortex has 1,000 times as many neurons as the same structure in a mouse, and it has not yet stopped evolving.

The smallest processing units in the cortex are known as neocortical columns, where each contains thousands of different connections. Over the course of evolution, these neocortical columns have been duplicated over and over again, until space in the skull started to run out. The cortex developed deep ridges and folds to fit more and more processing power into the same tiny space, and if unfolded, would cover an area measuring two square metres (21.5 square feet).

The neurons that make up the brain crisscross over one another in a vast network and each individual cell makes up to 10,000 connections, building the most complex circuit in history.

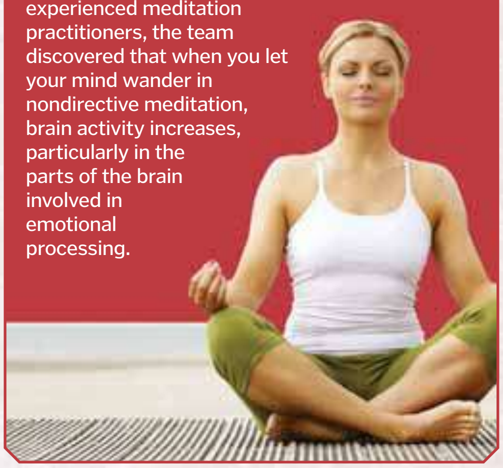
In 2013, a team at the Centre for Regenerative Therapies in Dresden, Germany, examined the formation of neuron connections in cloned mice. They wanted to learn how much the structure of the brain is influenced by life experience. Because the mice were clones, each was genetically identical, meaning that any differences in their brains would be purely down to their environment. The mice lived in large cages, with lots of toys and places to explore, and after just a few months, differences became apparent in their brains. The most excitable, outgoing, curious mice had many more new nerves and new connections than their lazier counterparts; their brains had adapted as they learnt.

While the underlying fabric of the brain is the same, every neuron in every brain is different, and each makes its own unique path. Every

Finding peace

Meditation has been practiced for thousands of years as a means to relax, think, or to find enlightenment. Now, an international team of researchers, based in Norway and Australia, are collaborating to understand why it is such a powerful tool.

There are two types of meditation; concentrative, where a person focuses on specific thoughts; and nondirective, where they let their mind wander. By studying fMRI scans of experienced meditation practitioners, the team discovered that when you let your mind wander in nondirective meditation, brain activity increases, particularly in the parts of the brain involved in emotional processing.



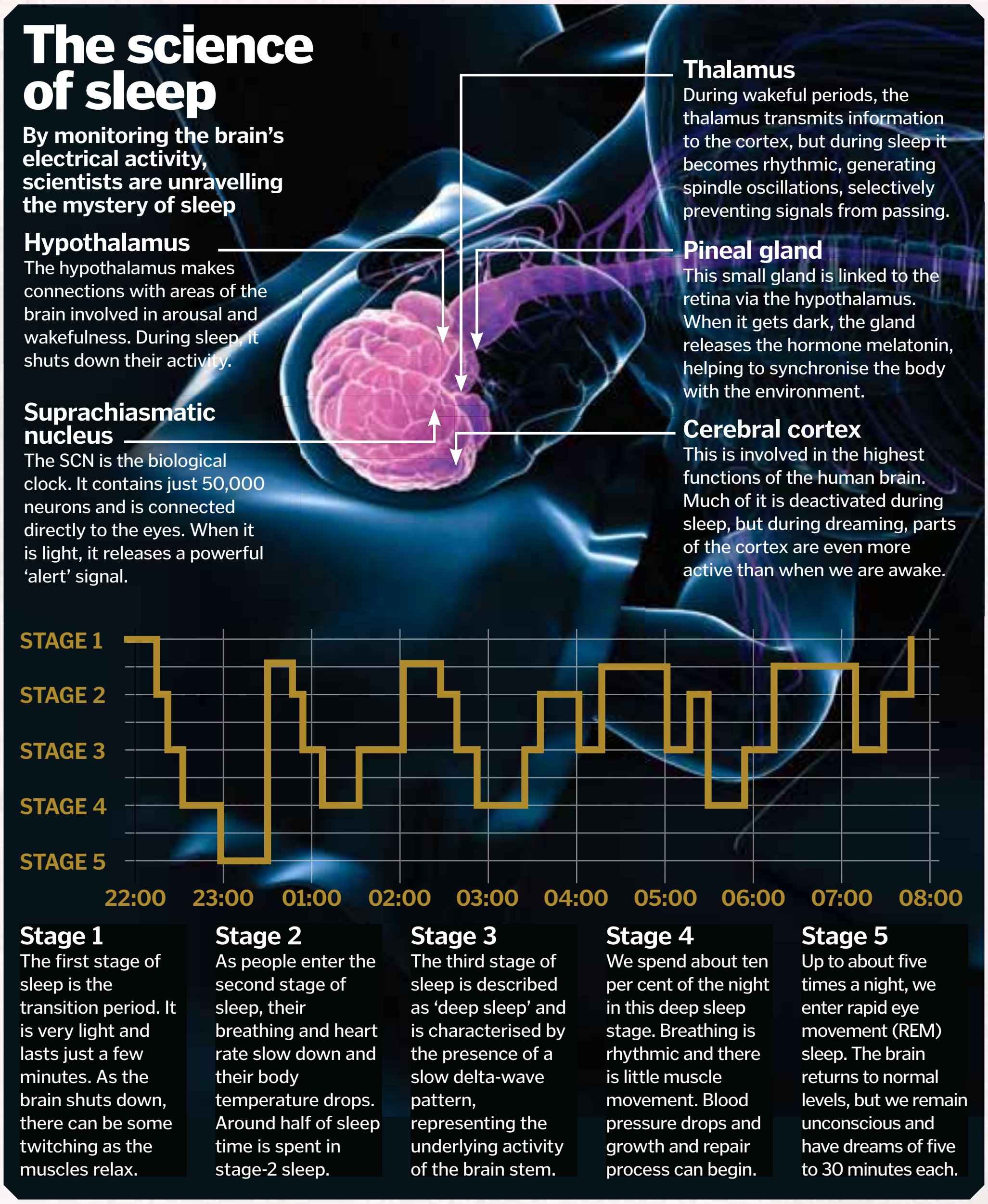
brain is wired differently, and the unique set of connections is based on experiences.

Mapping the connections in the human brain is an enormous task and work is ongoing. The Human Connectome Project, launched in 2009, is designed to map the intricate connections between all of the neurons in the human brain, in an effort analogous to the Human Genome Project. Computers can be programmed to trace the paths of neurons through brain-scan images, but even the most advanced machines make mistakes, and everything has to be double-checked by a human.

As an alternative, some research teams are trying a new approach, where instead of using computers to analyse the data they are using volunteers. In 2011, the online game *Foldit* made the headlines when players managed to solve a decade-old biological question. By tapping into the spatial skills of videogamers, researchers used volunteers to solve three-dimensional protein puzzles that a computer would struggle to complete. By simply playing the game, hundreds of people worked together to help solve the structure of a protein made by a simian retrovirus that causes AIDS-like symptoms in monkeys.

This approach is now being extended to the field of neuroscience and crowd-sourcing is being used to map the connections between neurons in the back of the eye. Tracking the intricate pathways of neurons in the brain is a difficult task for computers, but people are much better at spotting patterns.

EyeWire is a project designed to map the nerve connections in the human retina. Players are given a half-finished neuron and asked to work through slices of the brain, colouring in the connections. Each cube section is manually checked multiple times by different people, so



The developing brain

Baby
In order to fit through the birth canal, human babies must be born well before their brains have finished developing, so their brains grow rapidly in their first years. Experiences prompt the development of new connections between nerves, and by the time a baby is two years old, it has 1.5 times as many synapses as an adult.

Infant
Support cells, known as glia, provide protection, insulation and nutrition for the brain's nerve cells. Throughout childhood, they continue to migrate and grow. During the first two to three years of a child's life, the insulating white matter of the still-developing brain begins to form.

Child
By the age of ten or 11, the rapid development of new connections in the brain has ended and a period of trimming and pruning begins. Instead of creating extra pathways, the brain focuses in on the most important, strengthening and insulating those that are used more often and losing ones that are no longer valuable.

Making memories

The human brain has an amazing capacity for retaining information

SENSORY MEMORY
The body is constantly bombarded by sensory signals and most incoming sensory information is retained for less than a second before it is forgotten.

TRANSFER
The hippocampus integrates incoming sensory information, collecting it together as a single experience. It works together with the cortex to prioritise which information to store and which to forget.

SHORT-TERM MEMORY
Without concentrating too hard, short-term memory can hold around seven items for 20 to 30 seconds. Collecting information into discrete chunks, like splitting a phone number up into sections, can help the brain retain more.

IMPLICIT MEMORY
These types of memories do not require conscious recall and are often based on motor skills. By repeating tasks, like riding a bike or playing the piano, pathways become automatic.

EXPLICIT MEMORY
Explicit memories are accessed consciously. They can be stored as episodes, linked to a specific event or place, or stored by category as more abstract knowledge.

RECOGNITION
The brain is very good at making associations, and incoming information is compared to stored data, allowing us to quickly recall things we already know or have experienced before.

ASSOCIATION
Memories are rarely stored in isolation and one pathway is linked to others. Recognition and recall can both trigger other related memories.

RECALL
Human memory is associative; it works by linking pieces of information together. Memories are not stored as individual entities, but reconstructed using several different parts of the brain.

NEURON CHANGES
If a synapse is used repeatedly, it becomes increasingly sensitive to stimulation, producing more receptors and strengthening the connection.

ACOUSTIC ENCODING
Short-term memory tends to be based on sound, also known as echoic memory. When trying to remember a phone number, it often helps to rehearse it vocally in your head.

CONSOLIDATION
Once the trace of a memory is formed, the pathway can be consolidated with use. The more often a synapse is used, the stronger it becomes.

LONG-TERM MEMORY
The hippocampus is essential for the transfer of memories from short to long-term storage. Some of this memory consolidation happens in dreaming as the brain rehearses the day's activities.

SEMANTIC ENCODING
Instead of being linked to an audio memory, long-term memories tend to be stored more abstractly, by concept. Other memories are stored as sensory echoes, allowing entire experiences to be remembered and reconstructed.

Teenager
Trimming and adjusting the brain starts at the back and works forward, continuing into the teenage years. The prefrontal cortex, involved in planning, judgement and emotional control, is the last to be finished. Research also suggests that adolescents' body clocks are wired differently, so they naturally go to bed and wake up later.

Adult
Most growth and remodelling is complete by our early-20s, but new connections continue to form in the adult brain, albeit at a much slower rate than in children. Staying active and providing the brain with engagement and stimulation strengthens existing connections, and new pathways continue to form as we learn.

Old age
Damage to the brain cannot easily be repaired, so as it ages, signs of wear start to appear. Connections are lost as nerve cells wither, or as debris builds up between synapses, and gradually mental function can decline, leading to age-related illnesses like Alzheimer's disease and Parkinson's.

if someone makes a mistake it is averaged out by the community. More experienced players oversee the work and can make changes if they feel they are needed. This approach speeds up the process by thousands of times.

Although projects like EyeWire provide a detailed and biologically accurate picture of what is going on inside the human brain, rebuilding the entire structure using this method will still take decades. The alternative is to simulate the brain, taking what we already know and using it as a scaffold to build the parts we have yet to study. By going back and testing the model brain against the real data, scientists can check that their simulation is working as it should.

Japan's K Computer is one of the fastest and most powerful in the world, and in 2014, 83,000 of its processors were combined in order to simulate one per cent of one second of human brain activity. This was a huge achievement, but it took the machine 40 minutes and barely represented a fraction of the power of the human brain.

The problem is that most modern computers are built on architecture completely different to the human brain. The brain is made up of processing cores, capable of specialising to perform highly specific tasks. They are less precise, but have much more flexibility, and most importantly, the capacity to learn. Memories are not stored in one particular place, and are instead distributed across the network. In contrast, modern computers use programs in order to decide what to do, and they store elements in a hierarchical memory.

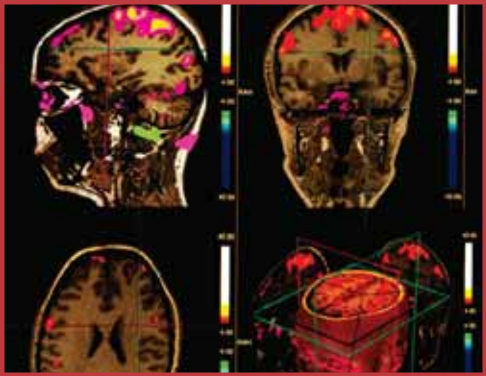
In 2013, the European Commission funded the Human Brain Project with a grant of €1 billion (£800 million/$1.3 billion) in order to accomplish just that. This ambitious, ten-year endeavour aims to develop cutting-edge computational tools to assist in the understanding of brain function, bringing together the fragments from different disciplines and providing an unprecedented map of human brain activity. The Human Brain Project hopes to use this information to build a supercomputer capable of simulating the network that makes up the human brain. They estimate that it would take one laptop to simulate the activity of one neuron and are working closely with IBM to develop powerful neuromorphic supercomputers.

Neuromorphic chips are computer chips modelled on the architecture of the human brain. IBM released a chip modelled on the human brain in 2014. Known as the SyNAPSE chip, it has one million 'neurons' connected by 256

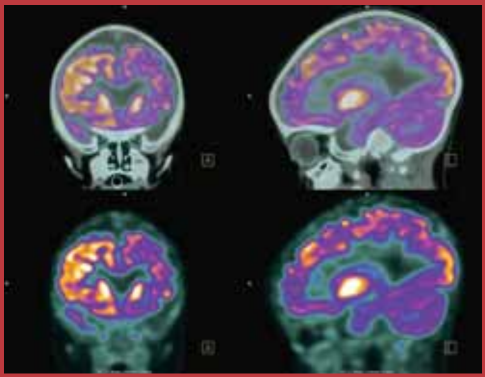
Imaging the brain

Take a look at the most common techniques used to study the living brain

CT
Computed tomography (CT) scans use X-rays to build a three-dimensional image of the brain. The radiation travels at different speeds through different tissues, allowing a density map to be produced. It provides purely structural information and is useful for identifying tumours.



fMRI
Functional Magnetic Resonance Imaging detects the amount of oxygen present in the blood, allowing brain activity to be mapped. When regions of the brain become more active, their demand for blood rises and they light up on the image. It captures a picture of the activity of the entire brain every two seconds.

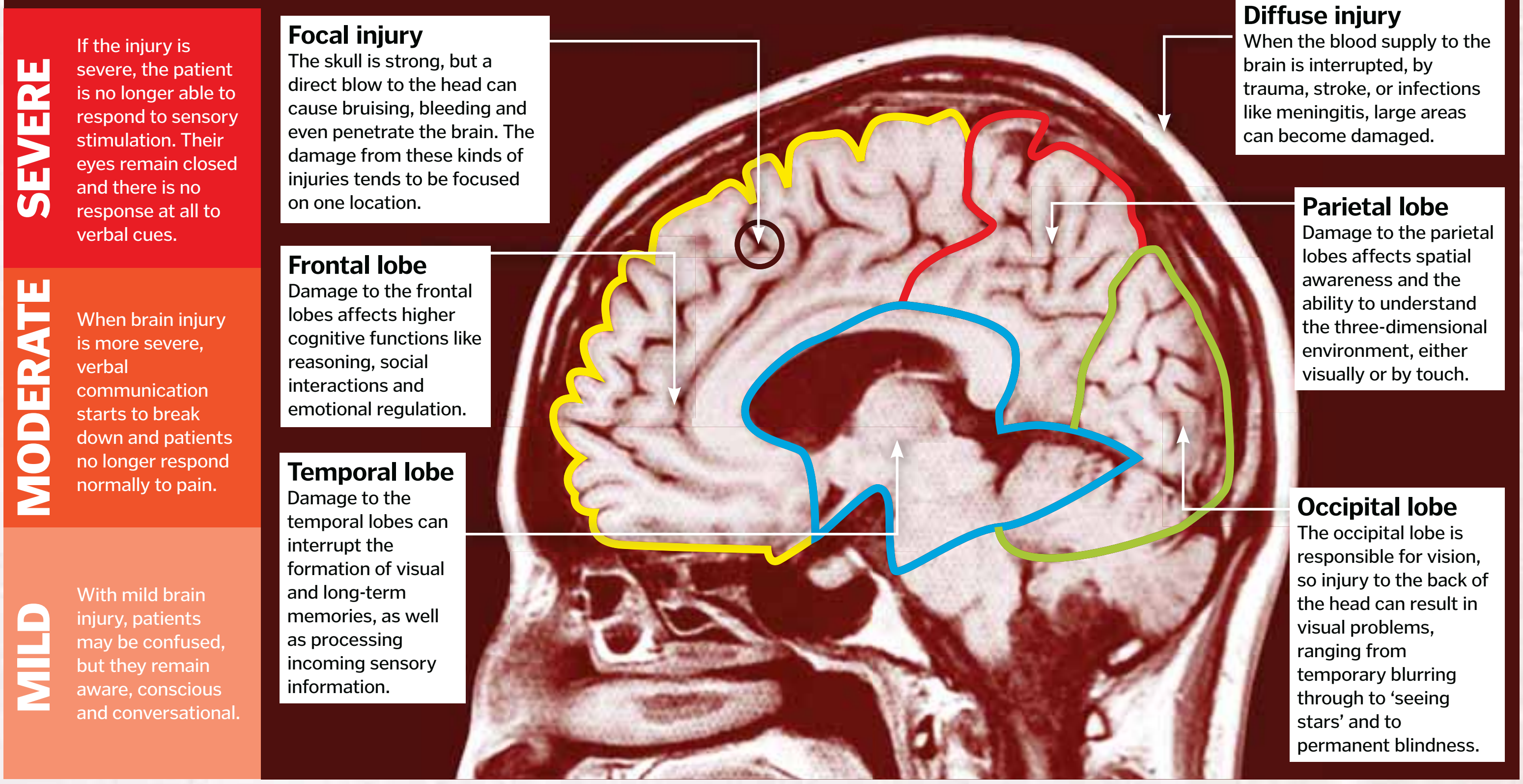


PET
Positron Emission Tomography uses safe radioactive isotopes to measure brain activity. By labelling oxygen or sugar with radioactive tags, blood flow in the brain can be monitored. The tags emit low-energy radiation and as blood is diverted to active regions of the brain, the emissions pinpoint the locations.

EEG
Electroencephalograms take advantage of the electrical signals produced by nerves to produce a map of brain function. Electrodes placed on the scalp are able to detect the patterns of nerve activity beneath the surface. This technique is particularly useful for sleep studies.

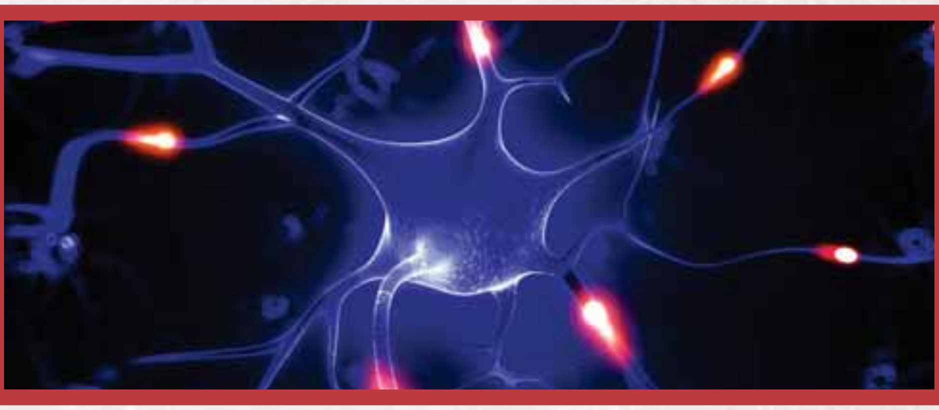
Brain damage

Different injuries affect the brain in different ways



Can the brain heal?

The human brain has limited capacity for repair, so once a region is injured, it cannot be replaced. The damaged cells are removed and support cells known as astrocytes divide to form a wall around the gap to seal off the area. The space then becomes filled with fluid. However, all is not lost. The human brain is a remarkable organ and although it cannot repair itself as such, it is able to adapt. Nerves are not fixed in their function, or their connections, so if a part of the brain is injured, new connections can be made to bypass the damage. The amount of function that can be regained depends on the location and severity of the injury and can be greatly aided by rehabilitation, encouraging the formation of new pathways in the brain.



million 'synapses.' They are arranged into 4,096 'synaptic cores', which function in parallel with one another, just like the processing cores in the brain. Just like the brain, they operate on demand and can compensate if one core happens to fail.

By feeding these computers with inputs that mimic biological signals, scientists can then examine the electrical activity and can see where information is being processed and stored. The project is a collaboration between over 100 institutions in 24 countries.

New technology is the key to modelling a structure as complex as the human brain, and other international efforts are also in place to provide new technology. In 2013, US President Barack Obama announced the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) initiative. The NIH (National Institutes of Health) will allocate £24 million ($40 million) in 2014 to develop new technologies to find the best way to understand the brain. In order to break the brain down and rebuild it accurately, the project will combine silicon-based techniques and advancements in stem-cell biology, brain imaging and medical drug development.

The practical applications of this future technology are incredible, but we are already able to interface with the brain in more ways than ever before. Light-sensitive retinal implants can restore sight to the blind by sending electrical signals to the optic nerve, while auditory brainstem implants communicate sound signals directly to the brain in patients who are profoundly deaf.

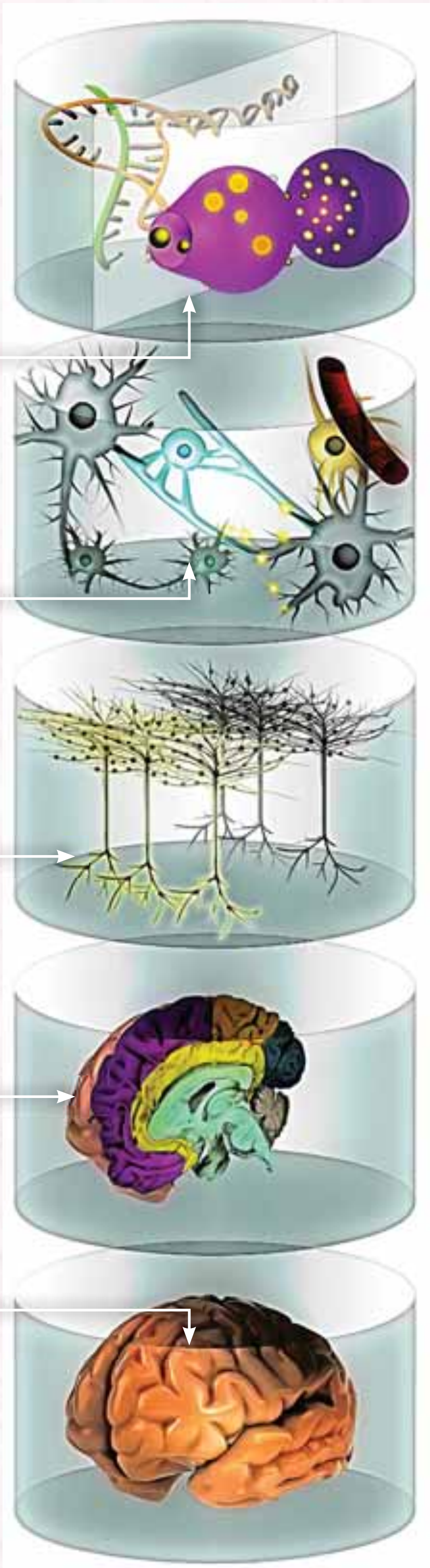
However, one of the most incredible technological developments of all is the BrainGate system, first revealed in 2006 and now undergoing clinical trials. The technology uses a sensor implanted on the motor cortex of the brain to pick up electrical signals generated when the patient thinks about moving. These signals are then decoded by a computer program and sent to a

Cutting-edge neuroscience

The human brain is one of the most complex structures in the known universe and understanding how it works is an enormous scientific undertaking. Modern neuroscience brings together experts from a huge array of fields and by using a combination of the most advanced technologies, medical techniques, biological research and computational modelling, scientists are finally beginning to untangle the many profound mysteries of the human brain.

Building a brain

Large-scale projects aim to simulate the human brain at every level



DNA and neurotransmitters

At the molecular level, scientists are able to manipulate the 3D structures of proteins using computer programmes, and to model the effects that changes might have. Such techniques are hugely useful in drug design.

Nerves and support cells

In order to gain a proper understanding of how the brain functions, many scientists advocate a bottom-up approach. By creating digital neurons based on the underlying rules and principles of biology, it is hoped that the complex network of the brain can be simulated.

Neural pathways

Some projects aim to map all of the connections in the human brain, generating a 3D representation of the intricate wiring. Others aim to simulate the process, allowing the computer to make its own connections based on biological rules.

Lobes and structures

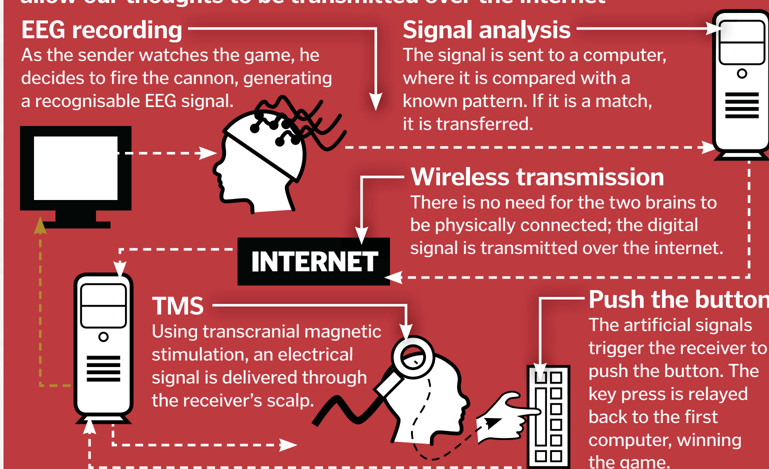
Simulations will allow information about different structures in the brain to be integrated, enabling scientists to more closely examine the interactions between different areas, or even to remove one region and study it in isolation.

Whole brain

In 2013, the K Computer in Japan carried out one second of simulated human brain activity. With 705,024 processor cores, it took the machine 40 minutes to simulate a network just one per cent of the size of the human brain. Advanced processors due in the next ten years will increase this capability significantly.

How mind control works

Simple equipment and complex computer programming allow our thoughts to be transmitted over the internet



EEG recording

As the sender watches the game, he decides to fire the cannon, generating a recognisable EEG signal.

Signal analysis

The signal is sent to a computer, where it is compared with a known pattern. If it is a match, it is transferred.

Wireless transmission

There is no need for the two brains to be physically connected; the digital signal is transmitted over the internet.

TMS

Using transcranial magnetic stimulation, an electrical signal is delivered through the receiver's scalp.

Push the button

The artificial signals trigger the receiver to push the button. The key press is relayed back to the first computer, winning the game.

Mind control

In a groundbreaking experiment in 2013, researchers at the University of Washington successfully linked two human brains together and proved their principle with a video game.

The city is under attack by pirates, where player one, the sender, must intercept their rockets. They can see the screen and are armed with a cannon, but they do not have a keyboard and cannot press 'fire'. Player two, the receiver, is sitting in another room; he cannot see the game, but he does have a keyboard. Player one thinks about firing the cannon, and fractions of a second later, player two pushes the button, saving the city and winning the game.

Player one was wired up to an electroencephalogram (EEG) and his brain activity was being monitored. When he was thinking about pressing the button, there was a characteristic signal in the 'mu band' of the EEG, triggering the program to send a wireless signal to player two.

Player two was wearing a specially designed coil on his scalp that generated a magnetic field, positioned over the part of the brain that controls contraction in the right hand. The signal from player one was converted into magnetic stimulation, which in turn triggered electrical activity in the brain, causing player two to involuntarily fire the cannon.

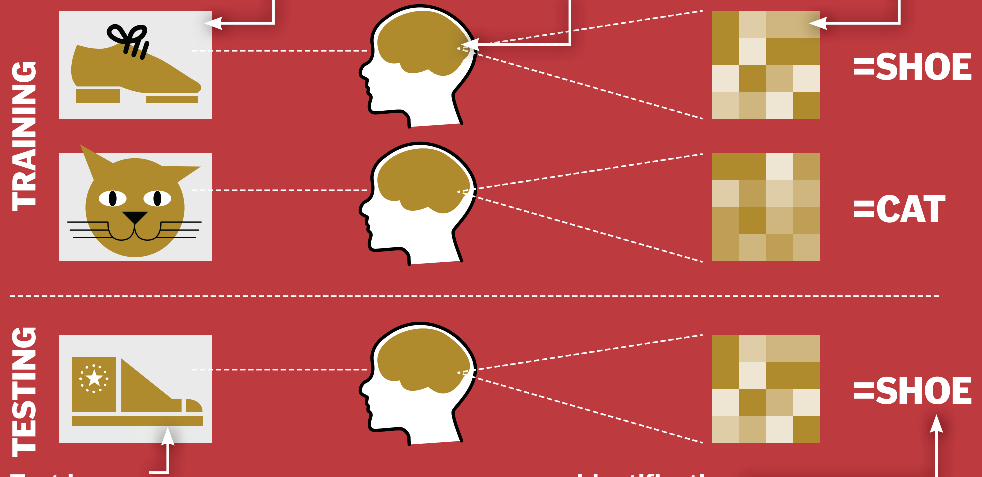
Decoding the brain

Computer programmes can learn to decode brain-scan data and essentially read our thoughts

Training images
The program is trained using a series of images, alongside their corresponding fMRI patterns.

fMRI scan
Functional magnetic resonance imaging is used to identify the parts of the brain activated by different visual stimulation.

Voxel pattern
The fMRI data is stored as voxel patterns, three-dimensional grids of information.



Test image
When the subject is shown a new image, the program searches through its training database to find the nearest match.

Identification
If the program cannot find an exact match, it will use its training data to find a best estimate.

A machine that can read your mind

Have you ever wished someone else could see what you can see? A team at the University of California, Berkley, have developed a program that can tell what film you are watching just by reading your brain activity. The program can even read the exact image you see and display the moving mental images on a screen.

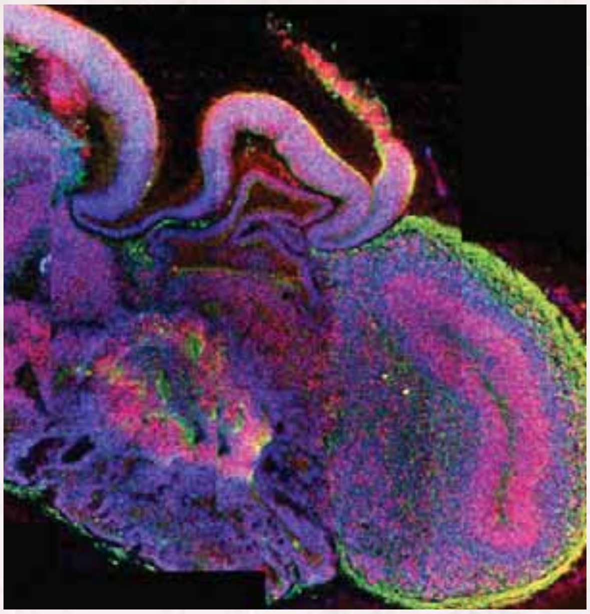
Volunteers were shown hours of video clips and for each one, their brain activity was mapped using functional magnetic resonance imaging (fMRI). The program was then trained to associate patterns of brain activity with their corresponding images.

Using this data set as a reference, the program was the shown new fMRI data recorded as people as they watched unknown clips. The program was able to compare the new data against its training data and guess what the test subject was watching by compiling and averaging the closest matches in to moving collages. The resulting pictures were eerily close to the original clips.

Growing a brain

In 2013, scientists at the Austrian Academy of Sciences achieved something incredible; they grew part of a human brain in a Petri dish. Using a combination of embryonic stem cells and stem cells taken from adult skin, the team recreated the neuroectoderm; the embryonic structure that goes on to form the brain and the spinal cord.

The cells were put in three-dimensional scaffolds to give them something to grow around, and then given nutrients and oxygen and allowed to develop. Amazingly, the structures organised themselves into something resembling the brain of a nine-week old foetus. Some contained the pigmented cells of a retina, others developed a cortex and some even had a hippocampus. These mini-brains are about the size of a pea, and incapable of conscious thought, but could provide a valuable tool for researchers.



Get involved with EyeWire

Citizen scientists are needed to help untangle the neurons of the human retina

Developed by the Seung Lab at MIT, this browser-based game, known as EyeWire, is a project designed to map the neurons of the retina. Anyone can play; all you need is a computer and an internet connection.

EyeWire is a 3D puzzle game based inside a cube. The cube is divided into slices and hidden within them is the path of a neuron. All you have to do is scroll through and connect the slices together, tracing the path of the nerve cell through the cube.

As you work, a 3D model of your progress appears to the side of the screen and you can earn points based on how closely your model matches the models made by other players. You can earn points, level up and even participate in weekly competitions.

Every time you play, you are mapping actual neurons from the human retina, making a real contribution to scientific research.

prosthetic limb. By carefully training the program to recognise specific signals, patients are able to move their bionic hands using just the power of their brains.

Taking electrical brain interfaces one step further, at the University of California, San Diego, researchers are using electricity to selectively erase memories. They have shown that by using particular frequencies of electrical pulses they can produce changes in the nerve cells in the brains of rats, making them forget traumatising experiences in their past.

As we continue to learn more about the connections in the brain, the possibilities for interacting with it will only continue to increase. The field of neuroscience is advancing faster than ever before, and huge international collaborations, like the Human Brain Project and the BRAIN initiative, are bringing mountains of research data together, creating resources that will revolutionise the field of neuroscience.

The puzzle of the human brain has been vexing scientists, doctors, and philosophers for thousands of years and understanding how it works is perhaps the most challenging problem in the history of science. However, with a combination of powerful new technology and international collaboration, the complexity of this mass of neurons is starting to unravel. Very soon, we might even be able to rebuild a functioning digital brain from the bottom up.

HOW IT WORKS

YOU ARE MADE OF STARDUST

The elements that make up our bodies were forged inside ancient stars

Words by Laura Mears

65% O OXYGEN

Oxygen makes up over half of our body weight. It is one of the key components of water, and is one of the three essential elements needed to make biological molecules like fat and protein.

18.5% C CARBON

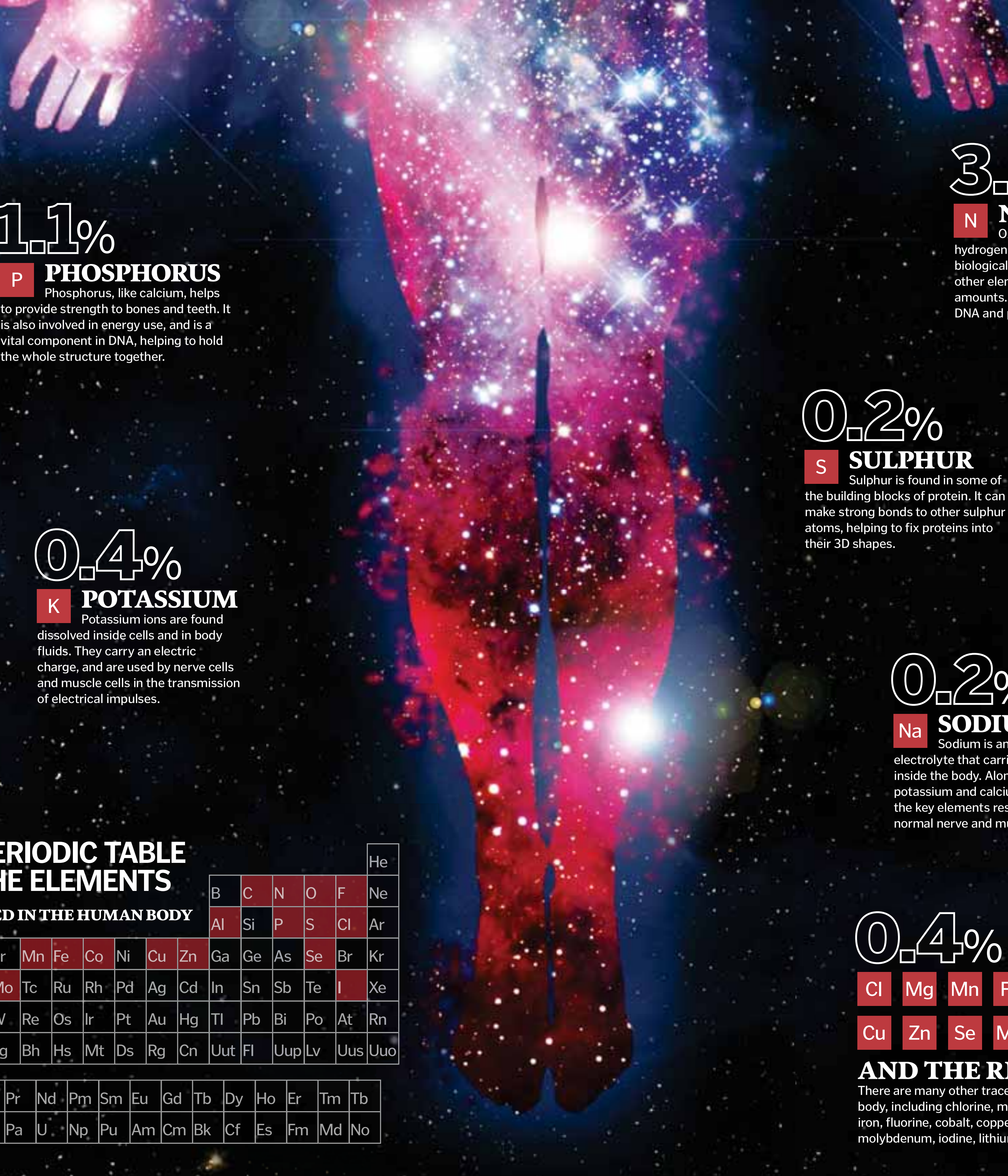
Carbon can make four bonds to other elements, making it the perfect scaffolding for building large, complex molecules. It is an essential component of fats, proteins, sugars and DNA.

1.5% Ca CALCIUM

Calcium is found in bones and teeth, and also plays an important role in signalling between cells, in muscle and nerve function, and in blood clotting.

9.5% H HYDROGEN

Hydrogen is the third element found in all biological molecules. There are actually more hydrogen atoms in the body than carbon or oxygen, but they are much lighter.



1.1%

P PHOSPHORUS

Phosphorus, like calcium, helps to provide strength to bones and teeth. It is also involved in energy use, and is a vital component in DNA, helping to hold the whole structure together.

0.4%

K POTASSIUM

Potassium ions are found dissolved inside cells and in body fluids. They carry an electric charge, and are used by nerve cells and muscle cells in the transmission of electrical impulses.

THE PERIODIC TABLE OF THE ELEMENTS

■ INCLUDED IN THE HUMAN BODY

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Fl	Uup	Lv	Uus	Uuo

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Tb
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No

3.2%

N NITROGEN

Oxygen, carbon and hydrogen make up the core of all biological molecules, but lots of other elements are used in smaller amounts. Nitrogen is found in both DNA and protein.

0.2%

S SULPHUR

Sulphur is found in some of the building blocks of protein. It can make strong bonds to other sulphur atoms, helping to fix proteins into their 3D shapes.

0.2%

Na SODIUM

Sodium is another electrolyte that carries charge inside the body. Along with potassium and calcium, it is one of the key elements responsible for normal nerve and muscle function.

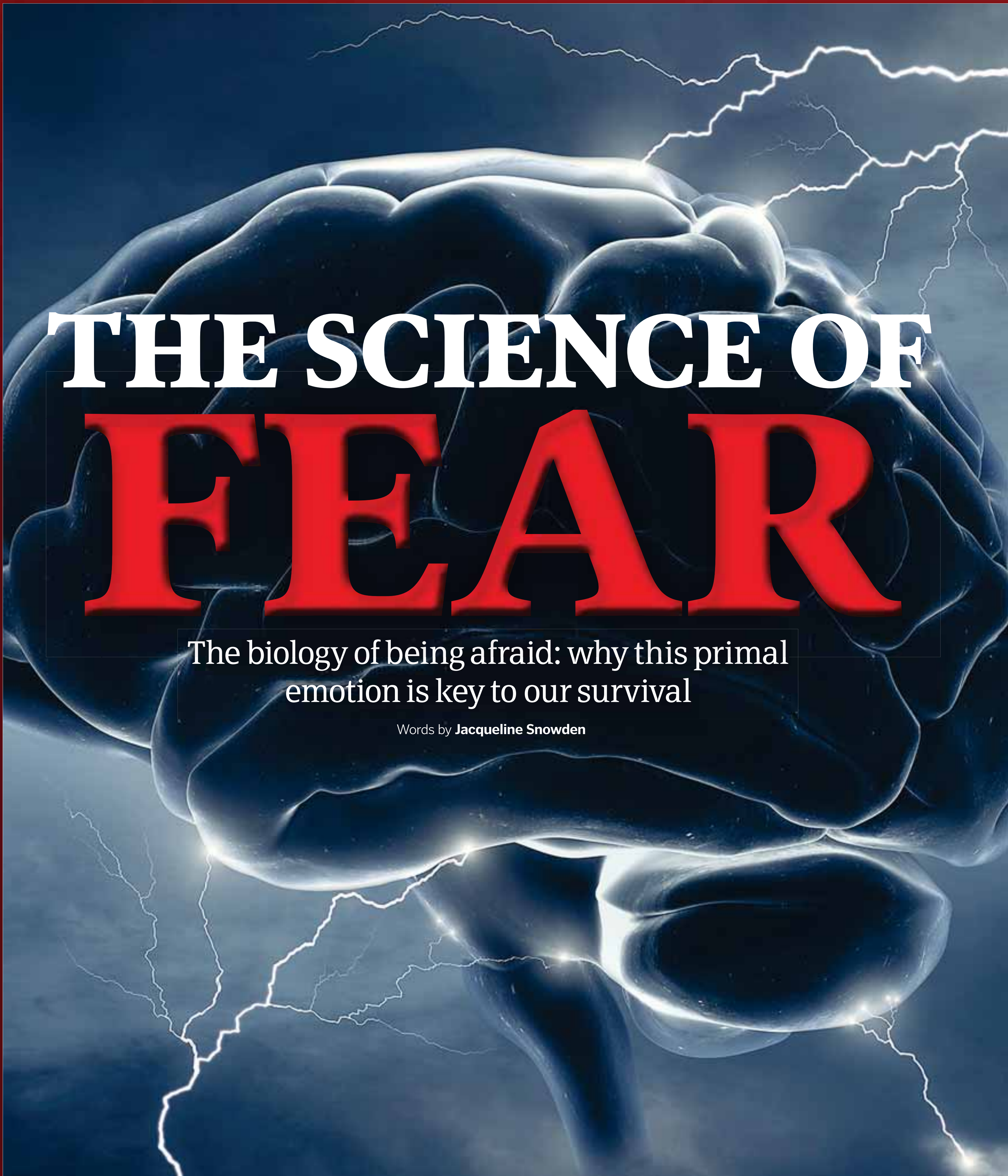
0.4%

Cl Mg Mn Fe F Co

Cu Zn Se Mo I Li Al

AND THE REST

There are many other trace elements in the human body, including chlorine, magnesium, manganese, iron, fluorine, cobalt, copper, zinc, selenium, molybdenum, iodine, lithium, and aluminium.



THE SCIENCE OF FEAR

The biology of being afraid: why this primal emotion is key to our survival

Words by **Jacqueline Snowden**

Home alone at night, you hear a loud crash. In an instant your heart starts racing, your muscles tense and your breath quickens. You are immediately alert, primed to fight or flee the source of the sound, which turns out to be a pile of books falling off that shelf you've been meaning to fix. But in that moment, your brain and body reacted as if you were in mortal danger.

Fear is one of our strongest and most primal emotions. It's a big bad world out there, and being afraid of certain things protects us from potential danger to make sure we survive. Some evolutionary fears are hard-wired into our brains, but we can also develop new fears throughout our lives. As children we pick up on what makes our parents anxious, and we may also learn to fear certain things after negative experiences. Despite this, most of us are able to ignore our fears when it's clear we aren't in any immediate danger. We can enjoy the view from the top of a skyscraper rather than worry about falling, or turn out the lights safe in the knowledge that a predator won't devour us in the night.

However, people with phobias have an excessive fear response that causes both physical and psychological distress. These extreme fears are divided into three different groups: agoraphobia, social phobia and specific phobias. Agoraphobia is generally referred to as the fear of open spaces, but it applies to the dread of any situation that is difficult– to escape from, or where help would not be available if something went wrong. Social phobia is the intense fear of interacting with people or performing, while specific phobias are the fear of a particular situation, activity or thing.

These irrational fears can cause major disruptions to everyday life; somebody with acrophobia – an extreme fear of heights – may experience a panic attack simply trying to walk across a bridge. Depending on the trigger of their phobia, sufferers often go to great lengths to avoid situations that could affect them.

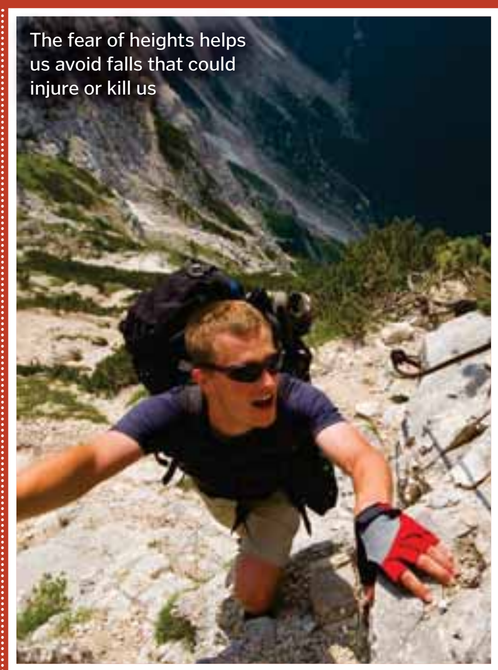
The cause of phobias is not always clear, but many cases are linked to experiencing or witnessing a traumatic event. For example, somebody may develop cynophobia – the fear of dogs – after being bitten. But whether the trigger is rational or irrational, as soon as the brain registers a scary stimulus, it activates the fight-or-flight response, thus preparing the body for action.

Natural fears

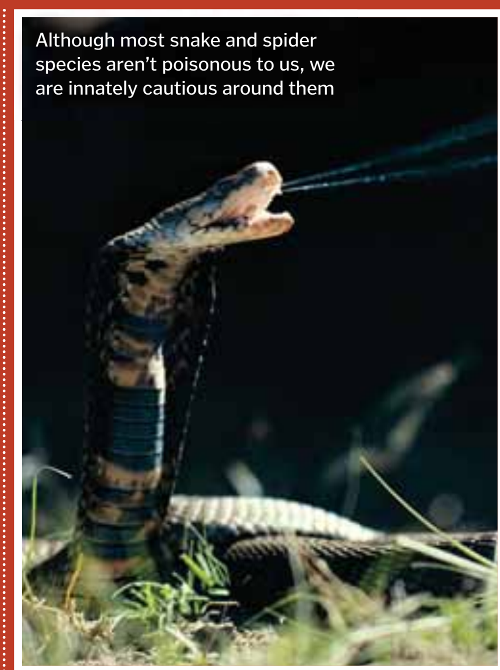
Some of our fears have developed as an evolutionary response to danger

"Even today, the majority of African lion attacks on humans occur after dark"

We are more afraid of what hides in the dark, rather than the darkness itself



The fear of heights helps us avoid falls that could injure or kill us



Although most snake and spider species aren't poisonous to us, we are innately cautious around them

Darkness

Sight is arguably our most important sense. When we are faced with pitch-darkness we are left vulnerable, unaware of what is around us. At night, our early ancestors were at risk of being attacked by nocturnal predators. A study from 2011 found that even today, the majority of African lion attacks on humans occur after dark, and are more likely when the Moon is below the horizon. Although being hunted while we sleep isn't a risk for most of us, we are instinctively more anxious when unable to see.

Heights

A fear of heights is necessary to our survival, ensuring we are cautious in situations where we might injure ourselves. To study this, researchers set up a platform surrounded by a transparent material, giving the illusion of a cliff, and put young children on the platform to test their reaction. They found that most infants didn't try to move onto the transparent section, suggesting that they inherently avoided risking a drop. As our ancestors explored the world, this fear ensured they were wary of climbing to dangerous heights.

Poisonous creatures

While we may not be terrified of them from birth, evidence suggests that we are predisposed to detect and recognise spiders and snakes quicker than non-threatening animals. One theory is that our early mammal ancestors, evolving in a world dominated by reptiles, needed to identify and react to snakes to avoid becoming dinner. Another hypothesis is that our ancestors evolving in Africa coexisted with a number of poisonous spider species for millions of years, so being able to spot and avoid them was a vital skill.


A fear of flying is relatively common, and may have roots in the evolutionary fear of heights

Fight or flight

How your brain and body trigger this evolutionary survival instinct

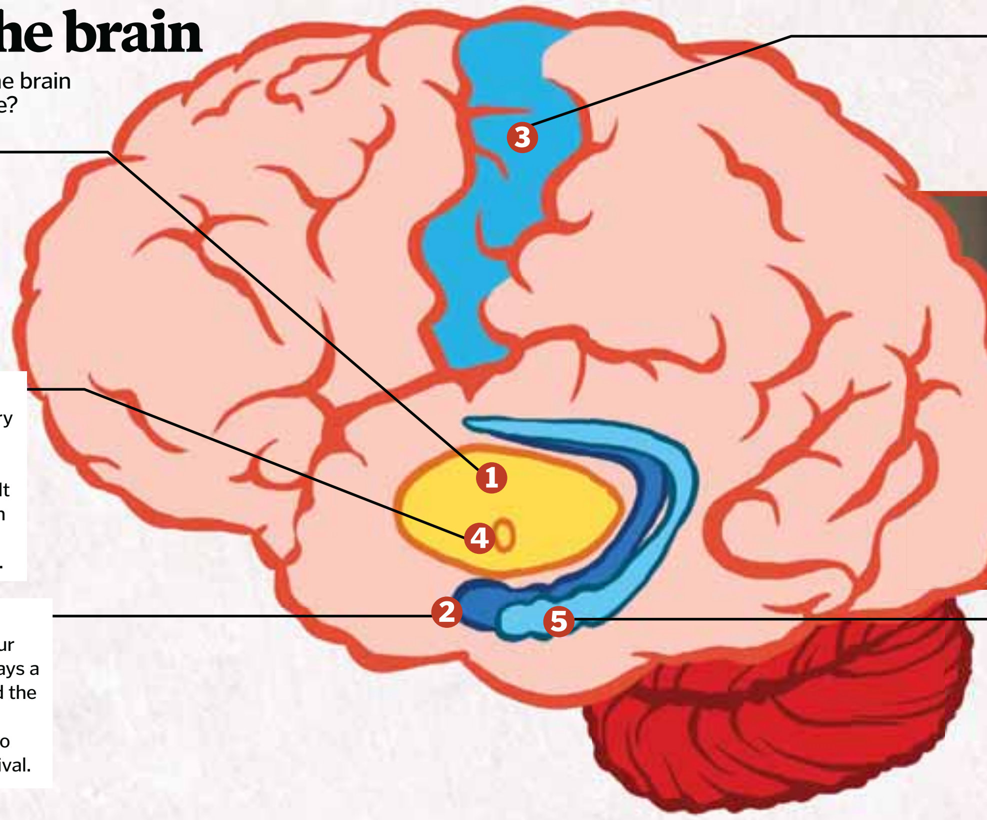
Under normal circumstances, sensory information from your body is sent to the thalamus in the brain. The thalamus relays these signals to the cortex and the hippocampus for further processing, to provide a better understanding of what you're experiencing and put it into context. This analysis is forwarded to the amygdala, which triggers an appropriate emotional reaction to the situation. When your brain receives signals that indicate some kind of danger, the course of action is slightly different. The process above still occurs, but this higher-level analysis takes precious time. The fraction of a second it takes to fully understand what's happening might be the difference between life and death. To make sure your body is instantly prepared to face a threat, the thalamus also sends the raw sensory information via a shortcut, directly to the amygdala. As soon as the amygdala is alerted, it signals the hypothalamus. This part of the brain activates systems that release a cocktail of around 30 different hormones into the bloodstream. One hormone in particular, adrenaline, causes a variety of physiological reactions all around the body. For example, in the lungs it makes smooth muscle cells relax, expanding the air passages so more oxygen can reach the blood. It also stimulates cardiac cells so the heart beats faster, and makes muscles in the eyes contract to dilate the pupils. The physical changes produced by this sudden flood of hormones make up what is known as the fight-or-flight response. This instinctive reaction gets you ready to either take a stand and defend yourself, or escape to safety.

Not many of us experience life-threatening situations day-to-day, so more often than not our fight-or-flight response is triggered by a false alarm. The moment of panic you feel after hearing a loud bang, for example, is because neural signals from the shortcut reach the amygdala first. The fight-or-flight response automatically kicks in before the brain evaluates the situation, just in case. Once the amygdala receives more information and concludes you aren't in danger, it signals the thalamus to stop the fight-or-flight reaction, returning your body to normal.

The human brain is hard-wired to prepare for the worst; it may seem silly to treat every loud noise as a danger, but if the threat turns out to be real, this overreaction could save your life.

Fear on the brain

What happens when the brain goes into survival mode?



Thalamus
The thalamus is the first port of call for most sensory signals from the body. It relays this information to the relevant areas of the brain, like a switchboard.

Hypothalamus
The hypothalamus's primary role is to maintain homeostasis – keeping the body in a stable condition. It also regulates the secretion of hormones and initiates the fight-or-flight response.

Amygdala
The amygdala processes our emotional reactions and plays a role in decision-making and the formation of memories. It moderates our responses to events that affect our survival.

Sensory cortex
Specific regions of the brain analyse the sensory information from each of our different senses. They process the signals passed on from the thalamus to give them meaning.

Hippocampus
The hippocampus plays an important role in long-term memory formation. It compares incoming sensory information to past events to help establish a context for the situation you face.

1 Stimulus
When a potential threat is detected, the thalamus sends signals to the amygdala via two different pathways. One route is fast and direct, while the slower path analyses the situation and decides what should happen next.

2 Act first
The first pathway immediately assumes there's danger even if there is none – a safer option than vice versa. It goes directly to the amygdala, which sends signals to the hypothalamus to initiate the fight-or-flight response.

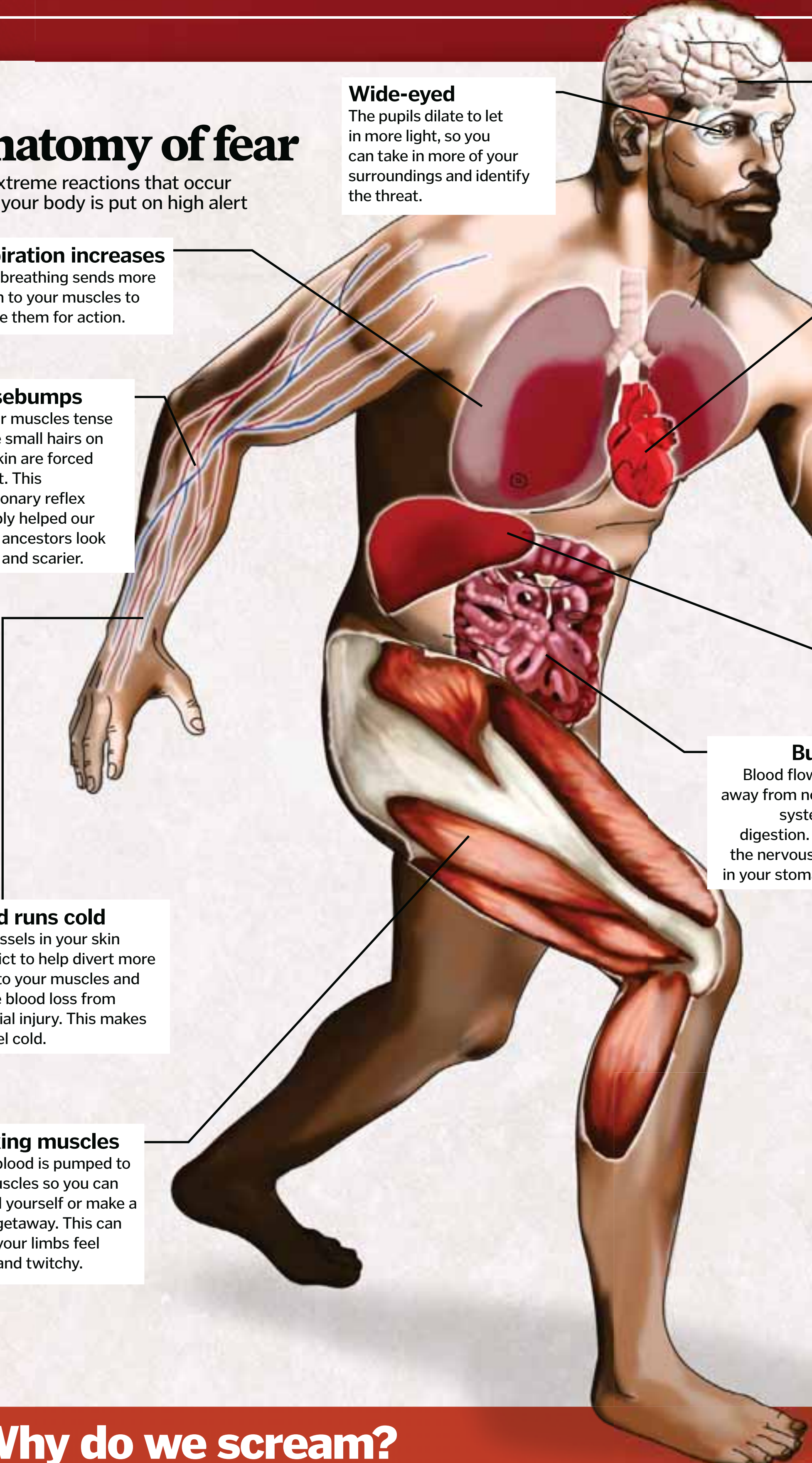
3 Analysis
The same information is sent along the more investigative route. Signals from the thalamus are sent to the sensory cortex, which interprets the data, followed by the hippocampus, to analyse the context of the situation.

4 Fight or flight?
The hypothalamus activates both the sympathetic nervous system and the adrenal-cortical system to trigger the fight-or-flight reaction. The impulses and hormones produced prepare the body for action.

5 Judgement
Once the situation has been analysed by the longer pathway, the hippocampus sends signals to the amygdala to either seize the fight-or-flight response if there is no danger, or to maintain it if there is.

Anatomy of fear

The extreme reactions that occur when your body is put on high alert



Wide-eyed
The pupils dilate to let in more light, so you can take in more of your surroundings and identify the threat.

Hormones
The activated sympathetic nervous system and adrenal-cortical system release dozens of hormones into the bloodstream to cause changes in the body.

Respiration increases
Faster breathing sends more oxygen to your muscles to prepare them for action.

Heart rate increases
The hormones adrenaline and noradrenaline are released to increase your heart rate, sending more blood to your muscles and brain.

Goosebumps
As your muscles tense up, the small hairs on your skin are forced upright. This evolutionary reflex probably helped our hairier ancestors look bigger and scarier.

Cold sweat
Your body anticipates immediate action, so you pre-emptively start to sweat in order to keep cool.

Butterflies
Blood flow is diverted away from non-essential systems such as digestion. This causes the nervous 'butterflies in your stomach' feeling.

Energy boost
Your liver starts breaking down glycogen into glucose, ready to supply the body with instant energy.

Blood runs cold
The vessels in your skin constrict to help divert more blood to your muscles and reduce blood loss from potential injury. This makes you feel cold.

Shaking muscles
More blood is pumped to the muscles so you can defend yourself or make a quick getaway. This can make your limbs feel tense and twitchy.

"The time it takes to understand what's happening might be the difference between life and death"

Why do we scream?

Screaming is an innate reflex; it's usually the first thing you do when you're born. Although we might also scream from excitement or pleasure, it is most often a cry of distress. Researchers from New York University conducted an experiment using brain scans to see how our minds react to screams. When we listen to normal speech, what we hear is sent to the auditory cortex for processing so we can make sense of the sounds.

However, the study showed that when we hear a scream, the signals are sent straight to the amygdala to activate the brain's fear response. The team also found that 'rougher' screams – those that change volume more quickly – were the most distressing. The results show that screams are a very effective method of communication in humans. They not only help convey danger, but also help make those who hear them more alert.

Screams are an example of a universal vocalisation; they are the same in every language

YOUR FIRST YEAR

What happens to the human body in the first 12 months of life

Words by **Laura Mears**

We are born well before we're ready to fend for ourselves, but we learn faster in our first three years than we will for the rest of our lives. So how do we get from vulnerable newborns unable to lift our own heads to walking, talking toddlers?

BIRTH

Babies enter the world with a lot of growing left to do. From around 35 weeks of pregnancy babies start becoming cramped. As the foetus gets bigger it demands more and more energy, and there's only so much that the mother can supply. Before they are born, their growth starts to slow.

Entering the world for the first time is a shock to a baby's system, and the first days of life are critical. Until the moment they emerge from the womb, their mother's body has supported every one of their needs. She maintains a constant temperature, digests food to supply nutrients and breathes to supply oxygen. She also deals with waste and fends off infection. Then suddenly the baby has to fend for itself.

As it hits the cold air of the delivery room, a powerful inward breath pulls its lungs open and fills them with air. In the safety of the womb, all the oxygen the baby needed came from the umbilical cord. The lungs were full of amniotic fluid and the heart diverted blood past them through a hole called the foramen ovale and a tube called the ductus arteriosus. Suddenly the baby needs to breathe. The hole in the heart slams shut and blood rushes into the lungs. Within hours or days after birth the tube, and another that carried blood from the umbilical cord to the heart (ductus venosus), closes too.

The other organ systems also spring into action. The baby has been practising breathing and swallowing in the womb, and the kidneys have already started working. Within 24 hours the gut starts moving, passing a dark green or black, tarry substance called meconium. It contains bile, mucus, amniotic fluid and anything else the baby has ingested in utero. Once this fluid is out of the way milk digestion can begin.

The newborn stomach is tiny – barely the size of a marble – so the baby needs to wake every few hours to feed. It can only take a few small mouthfuls at a time. The mother produces a thick, golden-yellow breast milk called colostrum. It's packed with energy but is lower in fat than normal breast milk, which newborns can find hard to digest. Instead, it's full of protein – perfect for a growing baby.

"Babies are born with vital reflexes built in"

Colostrum has a mild laxative effect, which helps to get the baby's gut moving, and it comes with a secret weapon: antibodies. These neutralise bacteria and viruses, sticking them together and triggering their destruction. Throughout pregnancy they cross from mother to baby via the placenta, but this type of immunity is only temporary. The baby will be able to make its own, but this takes a few months. In the meantime, colostrum provides a boost, helping to stave off infection.

The newborn has some tricks of its own to help it survive this vulnerable time. Though they have a lot to learn, babies are born with some vital reflexes built in. These include simple things like blinking, swallowing and yawning, along with more complicated responses.

The rooting reflex makes the baby turn their head or open their mouth when something touches their cheek or lip, and the suck reflex makes them suck if something touches the roof of their mouth. These instincts help with feeding.

Then there are the Moro reflex and the palmar grasp reflex. The first happens when a baby feels as if they are falling. They extend their arms and legs and arch their backs before curling up. The second makes the fingers and toes curl if you touch the palm of their hand or the soles of their feet. Together they help the baby to survive.

FIRST WEEKS

Brand new babies can hear and respond to noises and are born with the beginnings of communication. They will turn their head towards light and sound, make out the face of the person holding them and cry when they are in need. It only takes a few weeks for these skills to start to improve. They rapidly start to recognise the voice of their mother, and soon they begin to make different noises, cooing and gurgling as well as crying.

For the first few weeks babies can only focus on objects right in front of their faces, and their eyes frequently cross. At this stage their hand-eye coordination is poor. Very young babies will investigate their own hands and fingers, but they can't yet use them properly, and they often keep their hands in fists.

Inside, their bodies are undergoing rapid change fuelled by milk. If the baby is being breastfed, normal breast milk has now replaced colostrum. It's higher in fat and contains enzymes that help the digestive system to access the nutrients. It's also packed with sugars. Not only do these provide energy, they also help friendly bacteria to colonise the large intestine.

Babies are ready to try their first meal at around six months old

Why do babies sleep so much?

Brand new infants spend around 16 hours a day in the land of nod. At first they wake often to feed, but by the time they are 12 weeks old and weigh on average 5.7 kilograms they begin to sleep for longer periods.

Like adults, babies cycle through four sleep stages. They begin with the lightest dozing before a gradual drop into the deepest slumber, and this rhythm starts when they are still in the womb. Between these cycles they go through phases of rapid eye movement (REM) sleep, spending up to half of their sleep time dreaming.

Early work suggests that sleep is important for consolidating learning and for brain plasticity. In other words, it helps with the strengthening and pruning of connections between different nerve pathways in the brain. Some studies suggest that inadequate sleep may cause problems in the refinement of nerve connections. However, it's still early days and scientists need to do more research to confirm these findings.

TWO MONTHS OLD

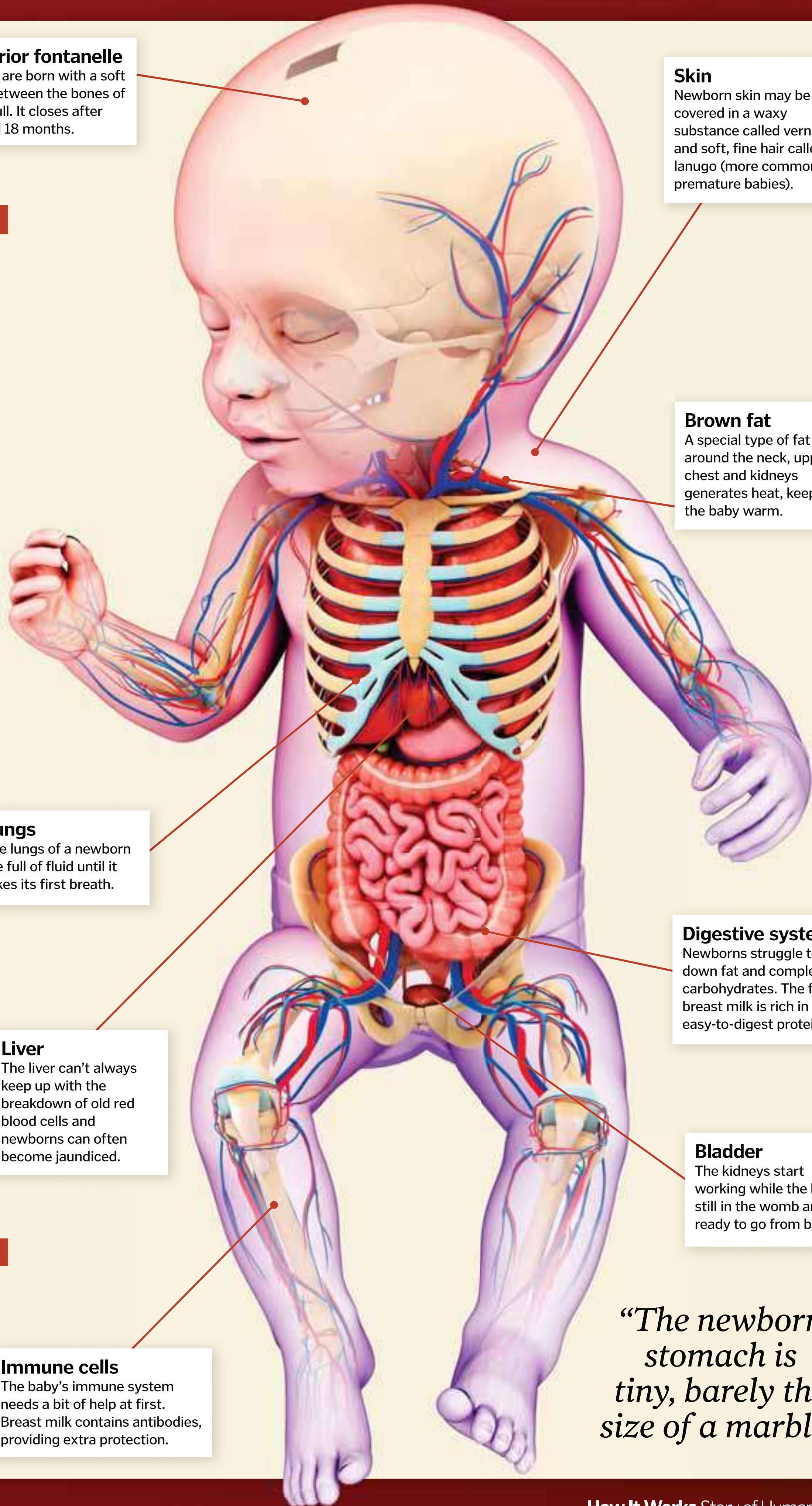
Babies spend much of their time eating and sleeping, and their bodies start to grow rapidly. In the womb, cells divide constantly to form tissues and organs, but after birth growth shifts. Rather than making new cells, babies increase the size of the cells they already have.

The tissues of newborn babies are very different to those of children and adults. There is more fluid around their muscle and nerve cells, and they have less cytoplasm inside. As the baby develops this balance shifts. Muscle cells expand, filling with cytoplasm and molecules involved in contraction. Nerve cells extend, strengthening connections and making new ones, and the amount of fluid outside these cells starts to fall. With newfound strength, babies learn to push up with their hands when placed on their tummies and start to hold their head a little steadier, their movements becoming less jerky and more coordinated.

Fat continues to quickly build up under the skin, helping to keep the infant warm. By the

BABY ANATOMY

Babies are more than just miniature adults – they have their own unique anatomy



"The newborn stomach is tiny, barely the size of a marble"

two month mark babies are already starting to develop social skills. They begin to follow things with their eyes and recognise people at a distance, and they begin to smile and laugh.

HALFWAY THROUGH

Babies can finally hold their heads steady at around 16 weeks of age. They will also start to push down with their legs if they're held above a hard surface, and by six months they can roll over, push up to a crawling position and even stand with support.

At around this time babies also begin to use their hands and eyes together. They reach for objects and rake with their fingers to grab them, and they start to use their mouths to explore objects further. With all this extra strength and coordination, the grasp and Moro reflexes are no longer needed. These early fail-safes fade away. Babies start to learn to pass toys from one hand to the other.

Their eyesight improves too. By this stage they are becoming more perceptive to the subtleties of different colours, and they start to copy facial movements. They recognise and express emotion and begin to find their voice. They blow raspberries and start to make consonant sounds like 'ba', 'da' and 'ga', using noise to get attention and to express themselves. They will also start to recognise words, especially their own name.

"To fuel all this progress, six-month-old infants often switch to solid food"

To fuel all this progress, six-month-old infants often switch to solid food. As the baby grows, the fat content of breast milk has been increasing from about 2g/dL of colostrum (grams per decilitre, equivalent to 100 millilitres) to 4.9g/dL. It has provided energy and contributed to a growing store of fat under the skin. But now the digestive system is ready for more.

A newborn's digestive organs are not only smaller than an adult's, but they also work differently. They make different quantities of enzymes and bile and they operate at a different pH. But at six months old things are starting to change. The first teeth come through, starting with the bottom front teeth then the top. Swallowing improves and the digestive system will start to produce enzymes to break down complicated meals.

FIRST BIRTHDAY

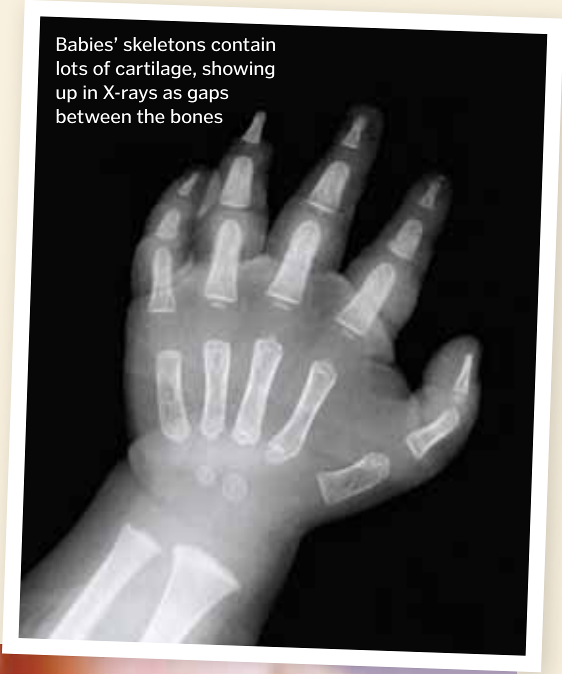
By their first birthday, babies are starting to develop complex behaviours. They have favourite things and favourite people. They start to understand 'object permanence's the idea that objects and people exist even though you can't always see them. They look for hidden objects and they begin to grasp the effects of gravity by learning to drop things and watching how they fall to the ground.

They also begin to respond to requests and make demands of their own. They will copy and use gestures like waving, pointing and head shaking. By now they will also understand familiar words and follow simple directions, as well as being able to help with tasks like dressing. Most importantly of all, they will start to communicate using 'babble'.

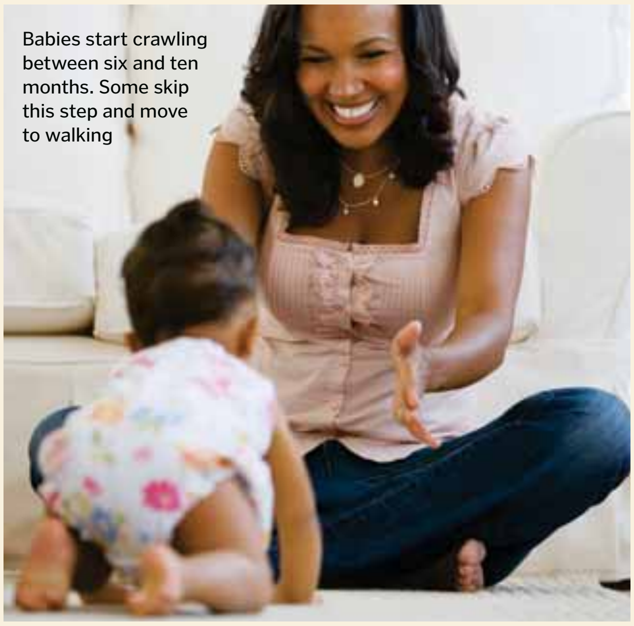
Their coordination has by now improved too. The grasp reflex is long gone, and they can move objects easily from one hand to the other. They can pick up small things between their thumb and forefinger and they will test new objects by shaking and banging. They will begin cruising, holding on to objects and moving around on two legs. Some may even take their first steps.

The hole that shunted blood through the heart when they were born is now fully healed over. Back teeth are starting to come through and the digestive system is processing full meals. The lungs have more air sacs, increasing surface area for gas exchange, and the brain has developed billions upon billions of new connections.

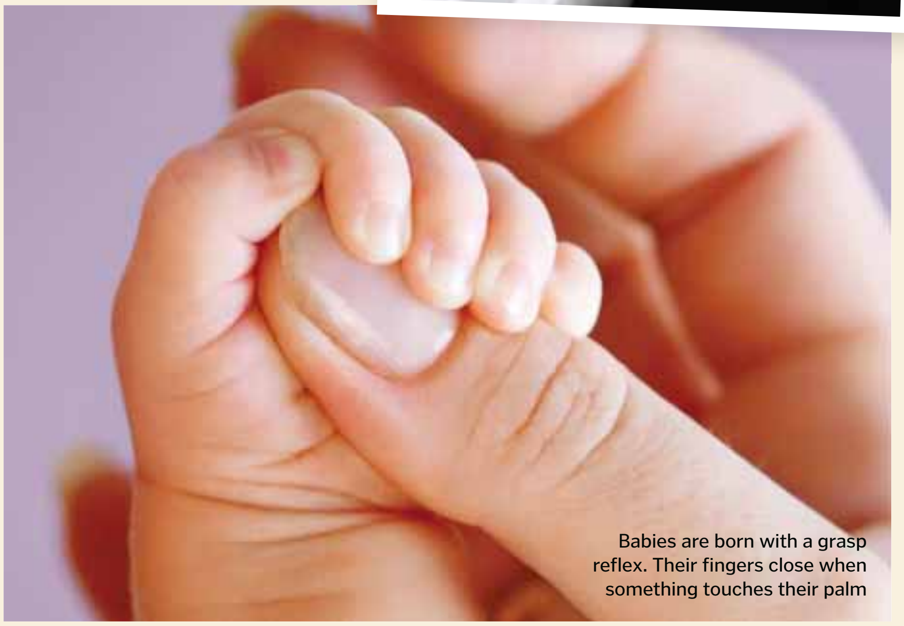
Over the coming months, babies transform into toddlers. As they begin to develop their understanding of the world, they start wanting to be more independent. They learn to walk, they start to talk and they even play games. Human babies are born tiny and vulnerable, but in a few short months they are already well on the way to growing up.



Babies' skeletons contain lots of cartilage, showing up in X-rays as gaps between the bones



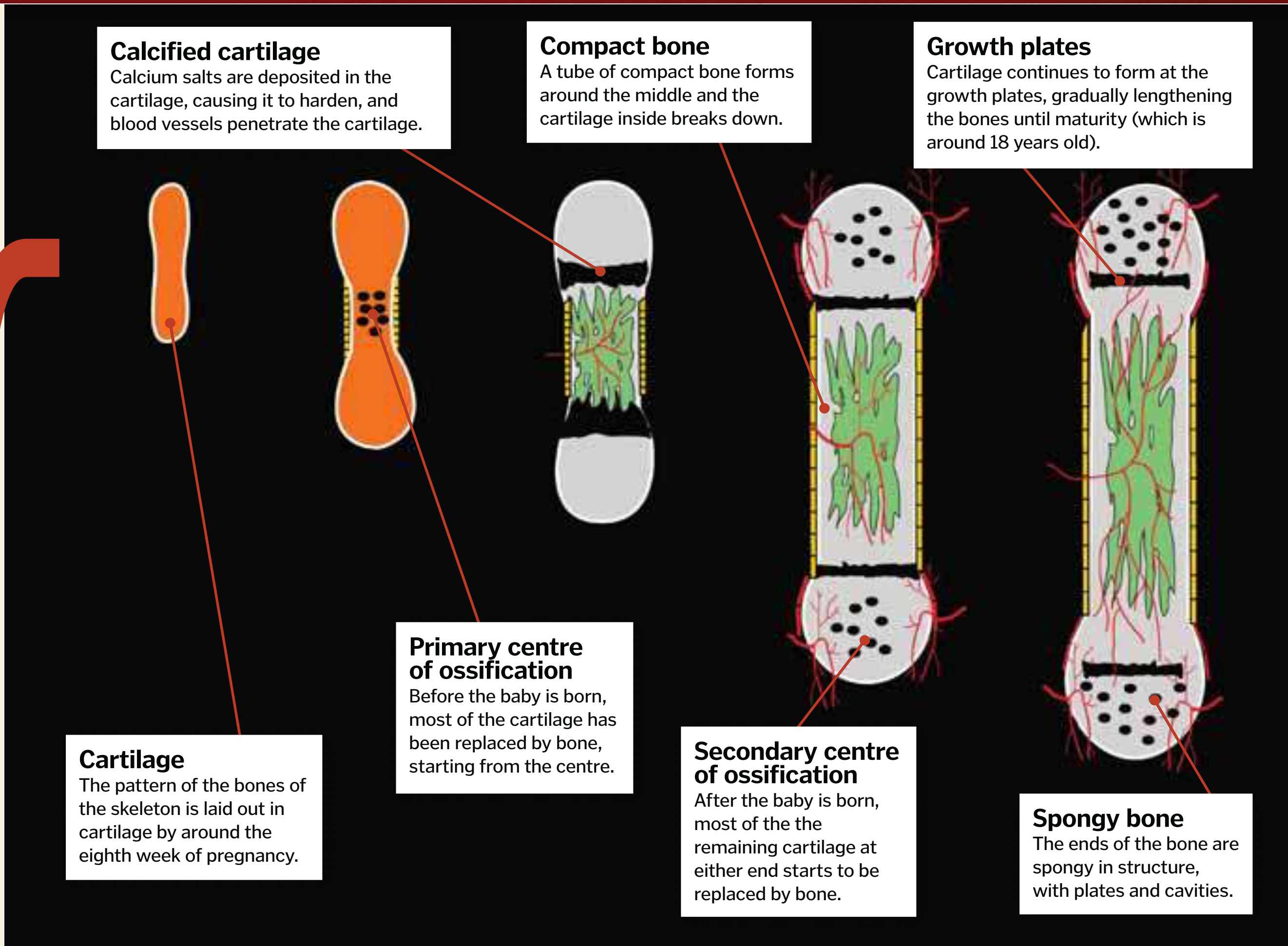
Babies start crawling between six and ten months. Some skip this step and move to walking



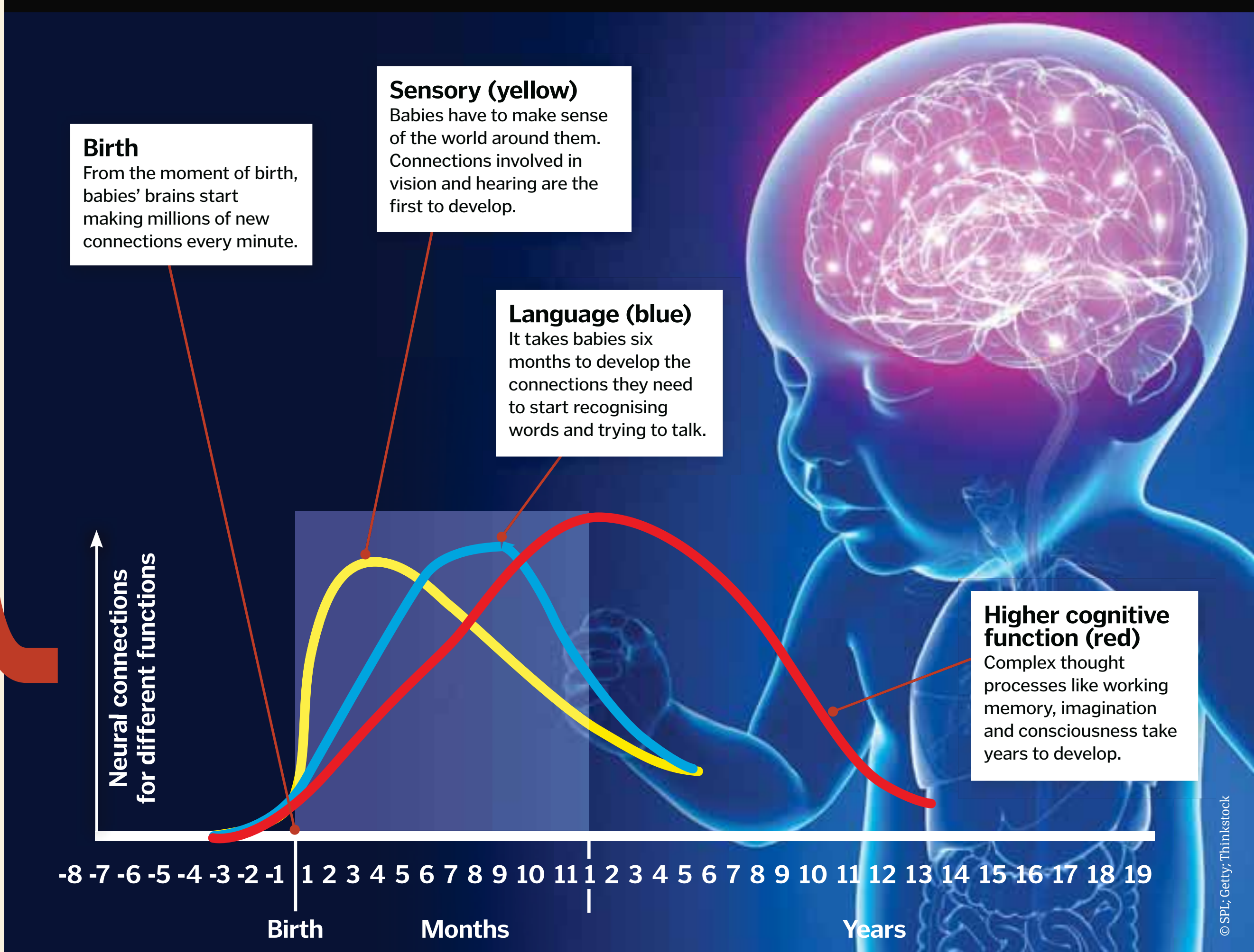
Babies are born with a grasp reflex. Their fingers close when something touches their palm

BRAIN DEVELOPMENT / HOW BONES GROW

Skeletons start out as cartilage and gradually turn to bone



Newborn brains grow from 25 to 90 per cent of adult volume in just five years



THE POWER OF IMAGINATION

The human brain has the unique ability to take what it knows and dream up something new

Words by **Laura Mears**

Can you imagine a purple dragon riding a bicycle with three wheels? No other animal on the planet has that power. You have the ability to take mental images of objects you've seen before, break them down into their component parts and rebuild them into something new.

Combine a reptile and a bird and you have your dragon. Recall the purple colour of a flower and you can paint its skin. Think about the mechanics of riding a bicycle and you'll be able to position its body on the frame, forelegs on the handlebars, hindlegs on the pedals. Now you just need to decide where you want to put that third wheel. This skill is incredible, and it's shaped the course of human history. Culture, engineering, art, science, music, technology: these things are only possible because we can make things up. But the ability to imagine hasn't always been there.

When modern humans first started migrating out of Africa around 100,000 years ago, they were still using the same simple tools as their ancestors. It was another 60,000 years before human creativity really started to explode.

Between the emergence of modern humans and the 'creative explosion', mutations in our genes slowed down the development of the brain's processor, the prefrontal cortex. This allowed the thinking part of our brain to get much bigger, and this in turn allowed our skills of visual processing and language to combine. Neuroscientist Andrey Vyshedskiy argues that this was the catalyst for imagination.

Of course, other animals can communicate and process visual information, but the way that we do it is unique. Scientists think that the ability to make mental pictures exists across the animal kingdom. It's a phenomenon known as 'imagery'. But it's not the same as imagination. Take bicycles, for example. When we see a bicycle, networks of neurons fire in the visual processing regions of our brains. To store a memory of what the bicycle looks like, the brain needs to remember which neurons lit up. To do this, it strengthens the connections between them. This is a principle known as Hebbian learning – 'nerves that fire together, wire together'.

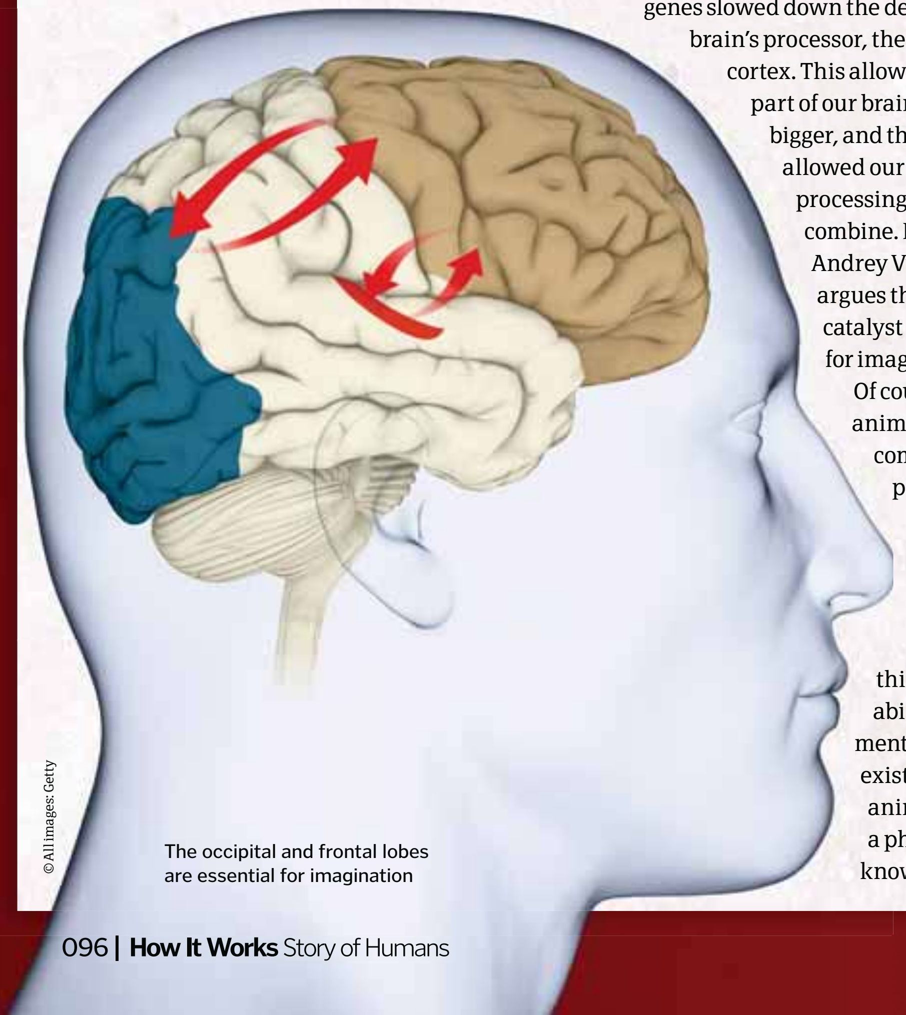
The result is that the brain forms a web of connected nerve cells that represent a bicycle, together known as a neuronal ensemble. To get the mental picture of the bicycle back, all the brain needs to do is reactivate the same connections. There's evidence that rats can do this to fill in the blanks when something's happening outside of their field of view; they use mental images to deal with missing information. But we can take it one step further.

Rather than simply recalling patterns we've already seen, we can use old patterns to invent something completely new. To do this, we borrow skills from the way we communicate.

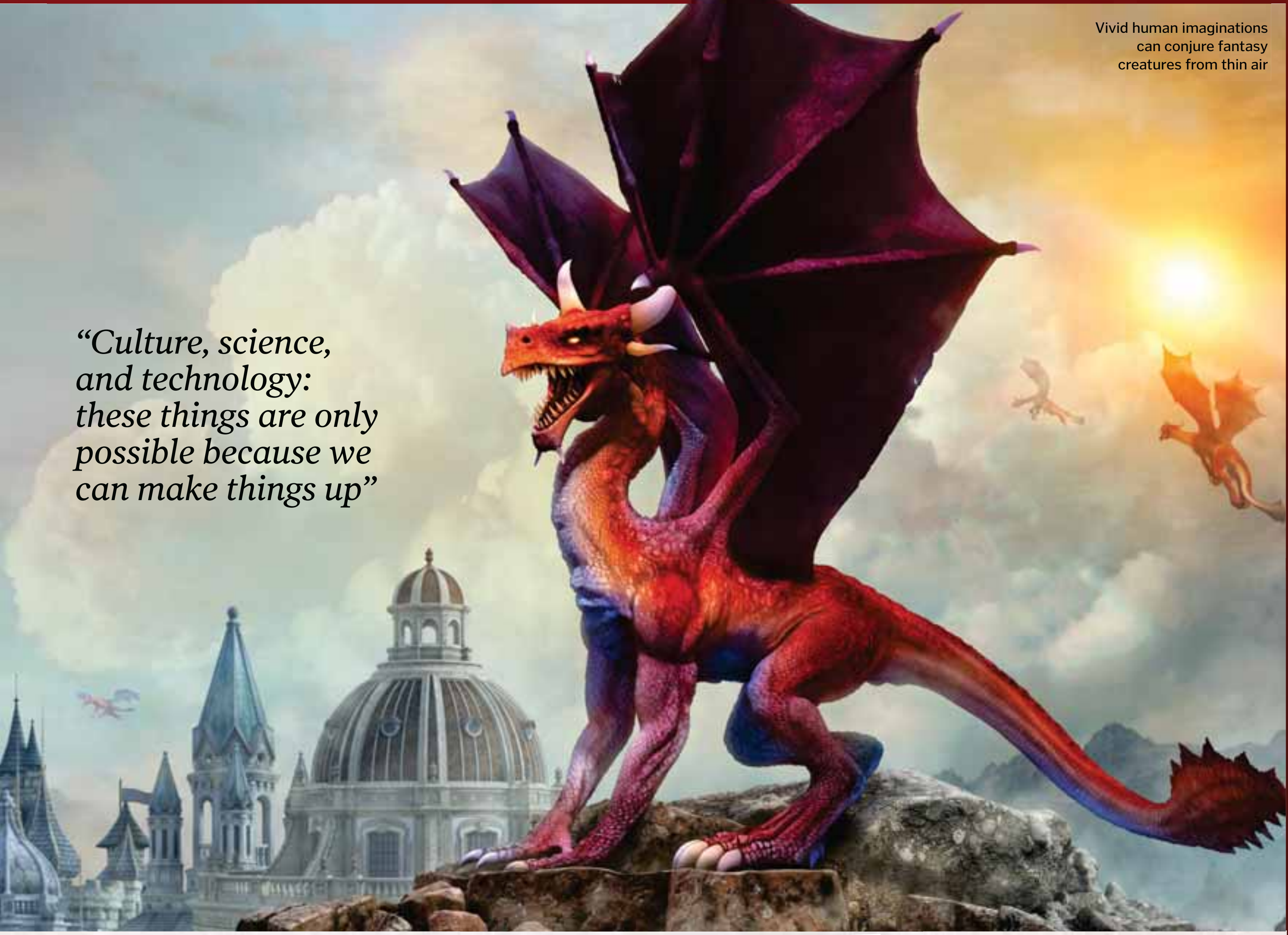
Other animals also have language, but none quite like our own. Across most of the rest of the animal kingdom, language is non-syntactic. This means that animals talk about whole situations all at once. A bit like reactivating the whole mental image of the bicycle. The thing we can do differently is break situations down and talk about them in parts, known as 'syntactic language'. This makes room for us to reassemble the parts in a different order or take parts of different ideas and combine them together.

It's the combination of syntactic language and mental images that make imagination possible. Together they allow 'mental synthesis': the ability to break visual ideas apart and put them back together to conjure up objects that have never existed.

To imagine a dragon riding a bicycle, we need to connect the mental ensembles for the



The occipital and frontal lobes are essential for imagination



Vivid human imaginations can conjure fantasy creatures from thin air

"Culture, science, and technology: these things are only possible because we can make things up"

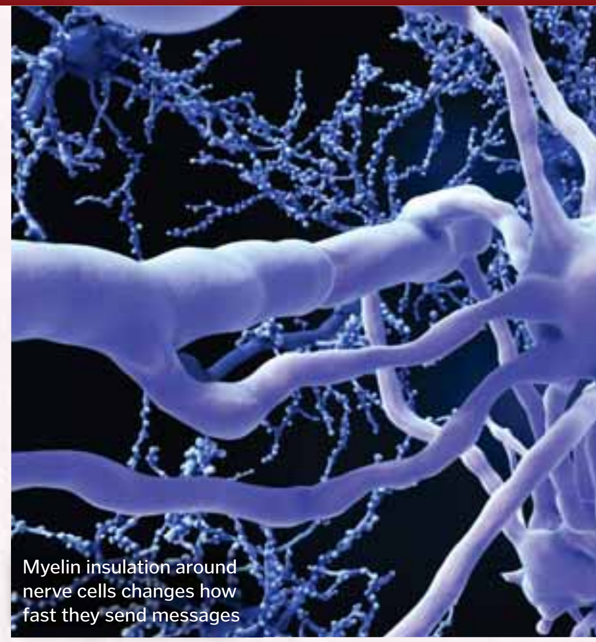
different concepts and activate them together. For this to work, the signals from different parts of the brain have to arrive at the same time, and this takes some coordination.

The connections responsible are neural fibres that link the prefrontal cortex to the occipital lobes. Different neural fibres have different lengths, so for imagination to work, the brain needs to change the speed at which they pass their messages. This helps to ensure that the messages arrive together. The brain does this by wrapping the fibres in varying thicknesses of myelin insulation: the thicker the wrapping, the faster the fibres transmit.

Changes to nerve fibre insulation happen during childhood, when our brains are at their most plastic. When we're young, our brains also prune and refine the connections between different brain regions. This makes childhood a critical time for developing the skills of imagination, and it's something we practise a lot. While other young animals might fight,

Your brain has stored a pattern of nerve cell activity that means 'bicycle'

Practising imagining as children allows us to use this powerful brain skill as adults



Myelin insulation around nerve cells changes how fast they send messages

climb and run to practise the skills they need as adults, our species are the only ones that seem to engage in make-believe. Imaginary friends are found nowhere else in the animal kingdom; we seem to have a unique gift for fiction.

The power of our imagination extends far beyond mental pictures of bicycle-riding dragons. Our brains contain 'mirror circuits' that activate not only when we do or experience something but when we see someone else do or experience the same thing too. For example, when we watch someone ride a bike, the centres in our brain that control movement light up. When we see someone fall off their bike, the parts of our brains involved in processing emotion switch on. These traces allow us to picture an experience in our mind's eye. And, like mental images, we can break them down and recombine them to imagine something new.

When children reach the age of around four or five, they also develop a complex imagination skill called theory of mind. This is the ability to understand that mental states – like knowledge, desires and emotions – can belong to us or

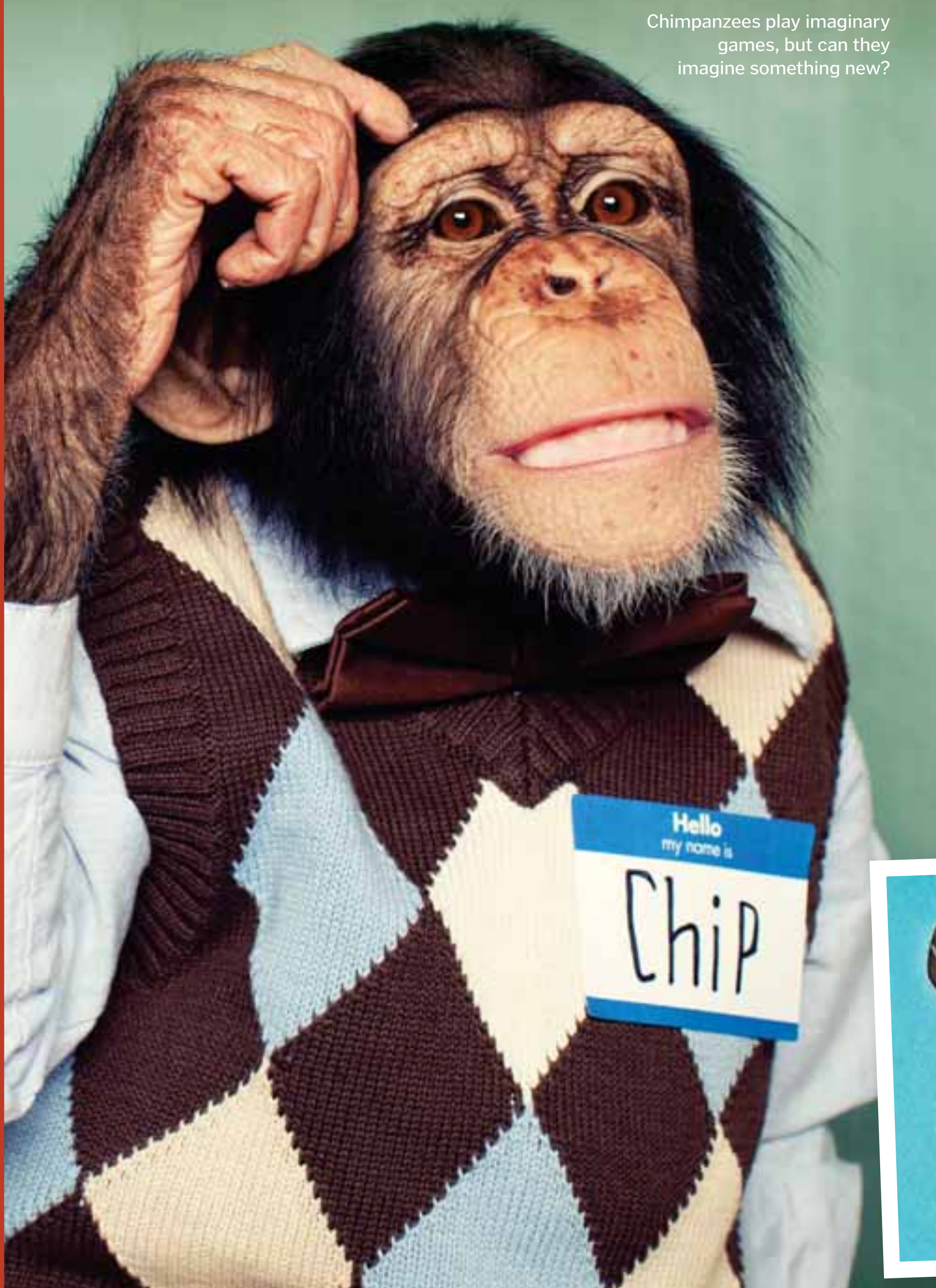
Can animals imagine?

Chimpanzees are our closest living relatives, but they don't seem to have the same powers of imagination as we do

Animals can make mental images of things they've seen before. They seem to dream, with parts of their brains lighting up in the same patterns that they did during the day. They might even be able to conjure mental pictures of potential future events, allowing them to plan ahead. But the question is, can they do what we can do and mash different ideas together to invent something completely unexpected? Perhaps not.

The search for animal imagination has led scientists to our closest living relatives, chimpanzees, and, like human children, they do seem capable of imaginary play. In a famous example, a chimpanzee named Viki pretended to pull a toy on a string, even seeming to stop to free it when it became stuck on an imaginary obstacle. Another chimp, Kanzi, pretended to hide food in bushes and then pretended to eat it. He even shared his imaginary food with others and watched to see whether they would eat it too. But in both cases, the chimps were imagining behaviours that they had experienced before.

The thing that animals don't seem to be capable of, as far as we know, is to imagine completely new things. This skill seems to be unique to our species.



Chimpanzees play imaginary games, but can they imagine something new?

Imagination enables humans to invent complex social contracts, like exchanging goods and services for money

Daydreaming allows the mind to find connections between different ideas

Imaginary friends might be uniquely human

belong to others. This lets us identify the goals of those around us, understand their beliefs and understand that what people say and what they mean aren't necessarily the same.

The neuronal ensembles that we build have many complex and interlinking components. It's the ability to take all this stored information, break it into parts and put it back together that makes our imagination so powerful.

By the time we reach adulthood, we have a sophisticated ability to plan ahead. We can run through potential scenarios in our minds and attempt to solve problems before they arise. This lets us prepare in advance. We can compare more than one possible outcome, prepare for both, or weigh up which is more likely. We can imagine things that have never existed and that will never exist. And we can run simulations to find out what it feels like to experience things we've never experienced before.

To access these superpowers of imagination, we use two large networks of brain cells known as the 'executive attention network' and the 'default network'.

The executive attention network sits between the outer parts of the prefrontal cortex and the parietal lobe. It taps into your short-term memory and is especially active when you're focused on solving a problem. This part of your imagination is laser-focussed, but its creative powers have limits.

A task as simple as rotating a shape in your mind's eye involves at least 12 separate regions of the brain. Brain cells communicate across these different locations, creating what scientists call a 'mental workspace'. But to create the focus needed to solve difficult problems like this, the executive attention network does its best to cut out distractions from other areas. This helps to get the job done, but it doesn't allow room for random thoughts, and it's randomness that makes imagination so powerful.

To access your full creative capacity, you need to relax into the default network. This is the part of the brain that lights up whenever your mind starts to wander. The main areas involved in the default network are the medial prefrontal cortex and the posterior cingulate cortex. Together, they handle memory, decision-making, reward and emotion.

When our attention is quiet and the brain enters a rest state, the default network takes control. The wandering mind is able to create and change mental images, recall episodic memories and relive thoughts and ideas, and by allowing many brain areas to be active all at once, it unleashes our unique human ability to integrate information.

One human imagination is powerful, but it's the combined imagination of the whole of humanity that has made our species such a success. It allows us to cooperate with other people on a scale much larger than any other organism on the planet, breaking down and recombining our shared experiences to reinvent the world around us.

Perhaps Albert Einstein put it best when he wrote, "Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution."

"We can imagine things that have never existed and that will never exist. And we can run simulations to find out what it feels like to experience things we've never experienced"

THE FUTURE OF HUMANITY

Are we still evolving?

Have culture and technology made 'survival of the fittest' obsolete?

The science of aging

Why we grow old, and what science can do to keep us looking and feeling younger for longer

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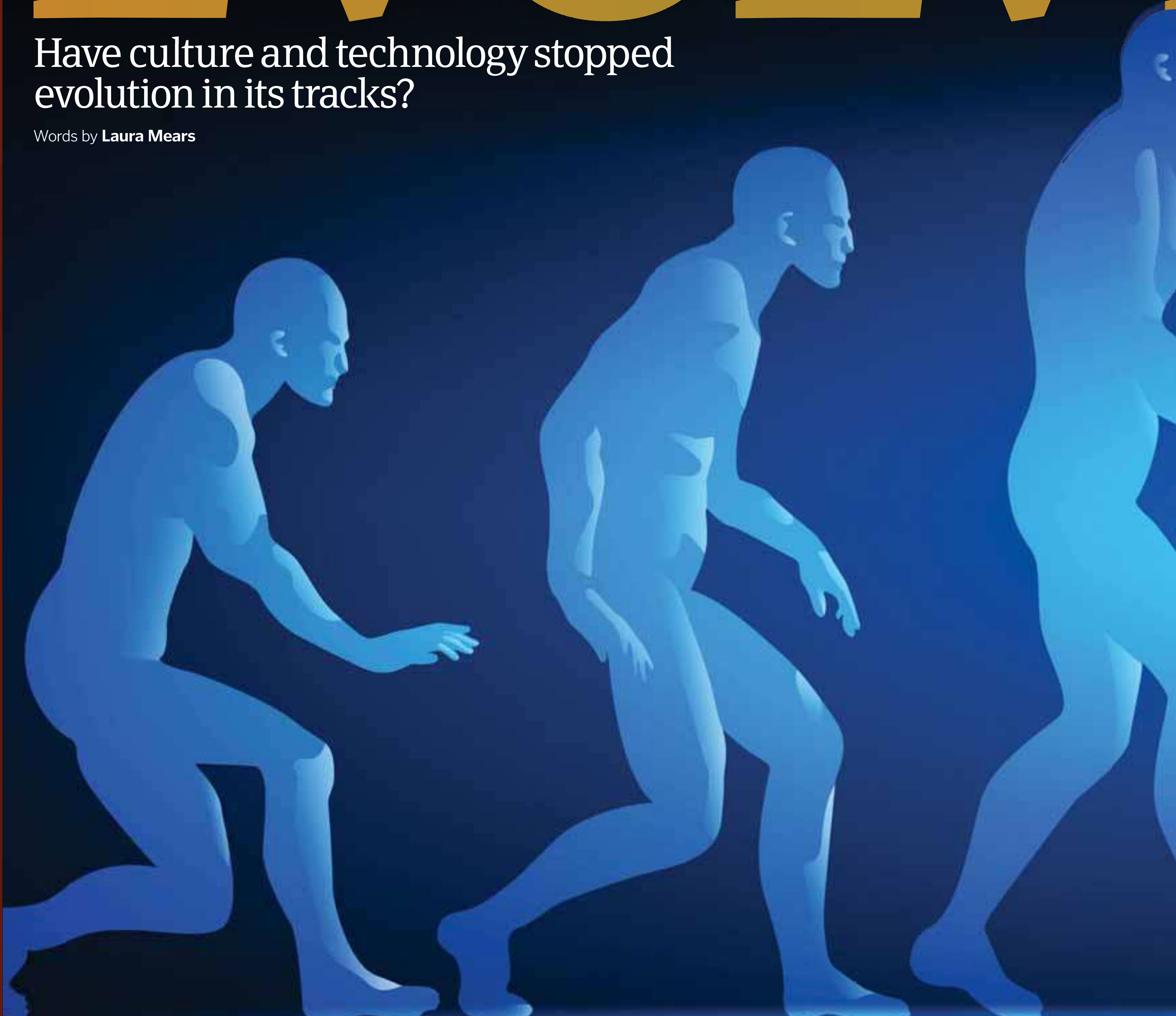
Humanity's greatest achievements

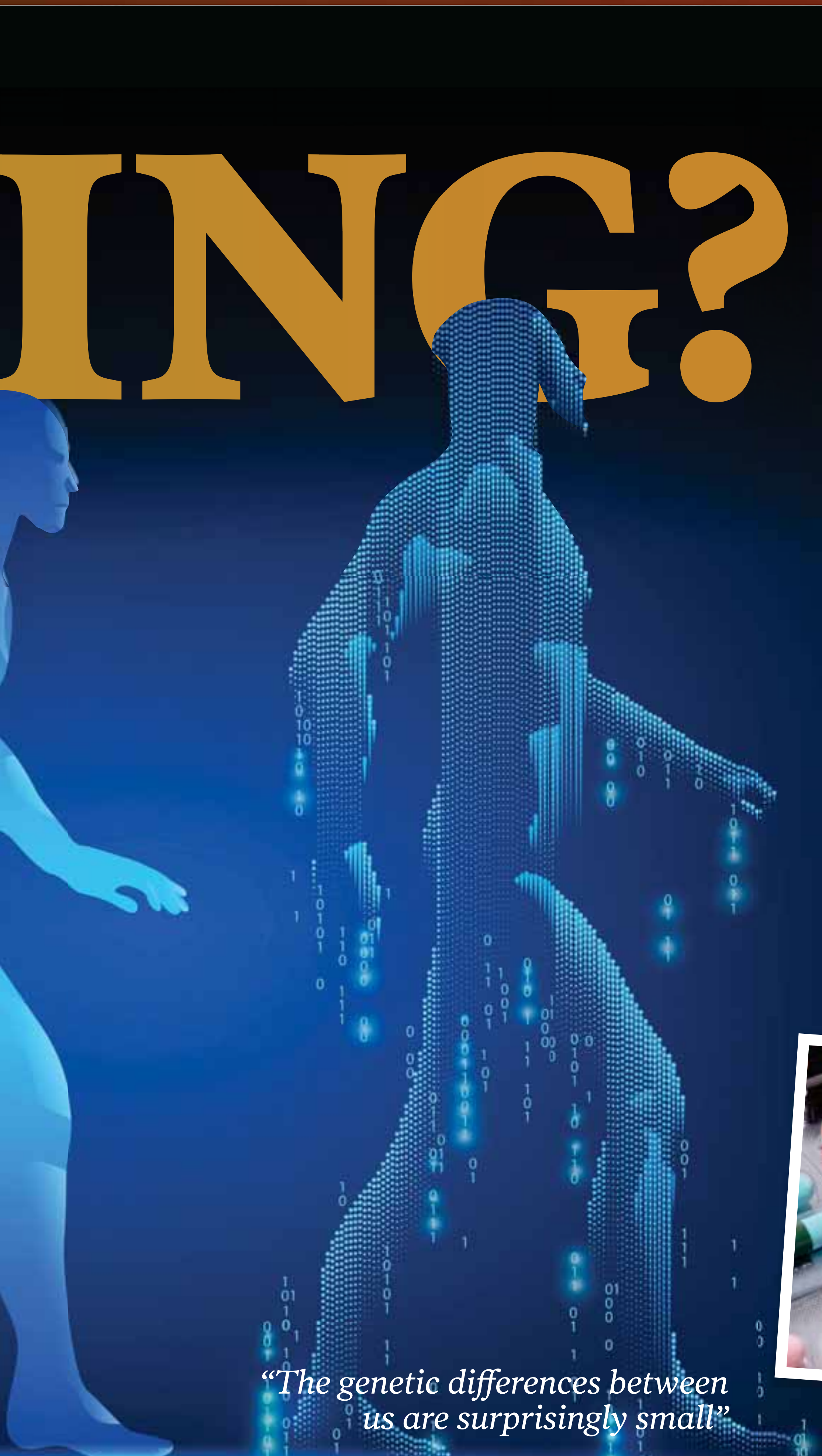
We've made some truly astonishing leaps forward during the past 100 years

ARE WE STILL EVOLV

Have culture and technology stopped evolution in its tracks?

Words by **Laura Mears**





"The genetic differences between us are surprisingly small"

Every human alive today can trace their ancestry back to east Africa around 200,000 years ago – DNA from a single woman still exists in every one of our cells. At the time, the human population was tiny, and her descendants are the only ones still alive today. They spread across the continent 100,000 years ago before radiating out in waves across the world. Scientists know the mother of humanity as mitochondrial Eve.

We may have dispersed, but the genetic differences between us are surprisingly small. There is no major distinction between people living on different continents or people of different races. In fact, there are more genetic differences between subspecies of chimpanzee. This similarity makes people question whether we've stopped evolving completely.

Evolution relies on a few key ingredients. Every generation, an organism makes more individuals than are able to survive. There are differences between those individuals, known as phenotypic variation. The cause of those differences, genes or genotype, are heritable, meaning that they can pass from one generation to the next. Some traits are better suited to the current environment than others. Individuals with those traits are more likely to survive and reproduce, passing the genes for their traits on to the next generation.

New traits enter populations in three main ways, the most well-known of which is mutation. When we make sperm or eggs, cells in our reproductive organs copy their DNA. This process is error-prone, so every time it happens mistakes creep in. This creates tiny changes in the genetic code that pass to the next generation. For the most part the differences don't do anything useful – or harmful. The mutations are often silent (they do nothing) or neutral (they do something, but it doesn't make a difference). In fact, many mutations aren't even in genes;

Modern medicine reduces the pressure of illness on our species

they're in the DNA that sits between them. However, sometimes mutations change the way a gene works.

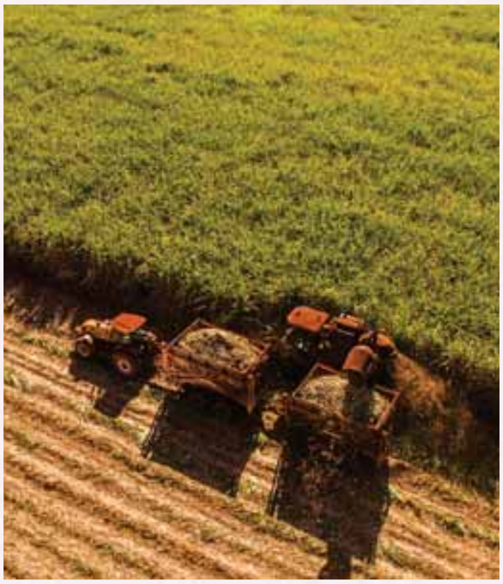
New traits can also enter populations via gene flow. This happens when groups of people separate and then come back together, sharing new genetic information. Finally, traits change because of sex. Babies inherit genetic material from both parents, putting new combinations of genes together.

Over the past 100,000 years these three mechanisms have changed the traits that make us human, but we are still young in evolutionary terms. We take a long time to reproduce, and there's a limit to the amount of variation that can accumulate in a few hundred thousand years. Your genetic information only differs from mine by around 0.1 per cent, and most of those differences are single letter changes. Despite outward appearances, the whole human population still shares close family ties.

Our genes are always changing, but genetics is just one piece of the evolutionary puzzle. Our environment has a huge role to play in how our species evolves. For new traits to pass from generation to generation they need to change our chances of survival. This is where Darwin's natural selection comes in. If a genetic change makes an individual more likely to reproduce they have a better chance of passing on their genes. We know this as 'survival of the fittest', but it's not always about being the biggest, strongest or fastest. It's about having traits that let you make the best use of your current environment. As the environment changes, so do the kind of mutations that might be useful.

This is where human evolution gets complicated. We can change our environment with culture, science and technology, messing with natural selection. If you look deep into history, our human-like ancestors were at the mercy of their environment. Lucy, a famous fossil of a species known as *Australopithecus afarensis*, lived 3.2 million years ago. She had ape-like characteristics, including a large jaw, long arms and a covering of fur, but she walked on two legs. She lived in the trees like other apes, but the environment was changing, trees were disappearing, and Lucy was spending more time on the ground. Eggs found near her remains suggest she might have been foraging.

Between Lucy and mitochondrial Eve, climate change eventually forced our ancestors out of the forests and onto the plains. They had to run



Agriculture gave us stable access to food, freeing up time for science

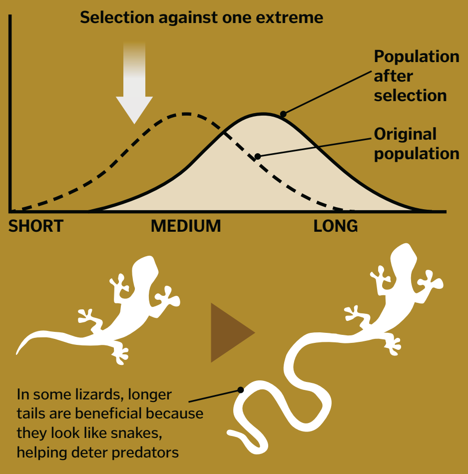
"Your genetic information only differs from mine by around 0.1 per cent"

Types of selection

Three laws of natural selection govern evolution, but other selective factors can play a role

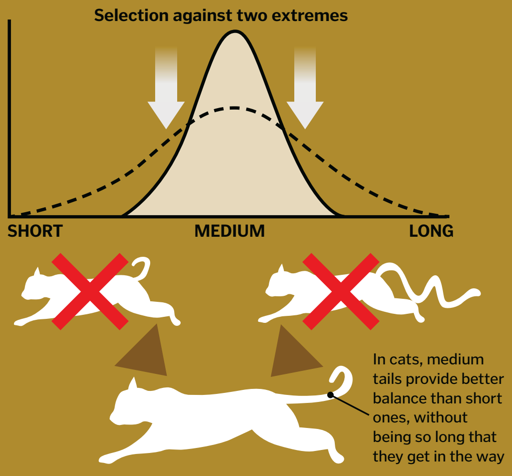
Directional

If the environment changes, it forces organisms to adapt. Directional selection pushes traits in one direction, towards a new solution. Once they find the solution, traits can stabilise again, unless the environment keeps shifting.



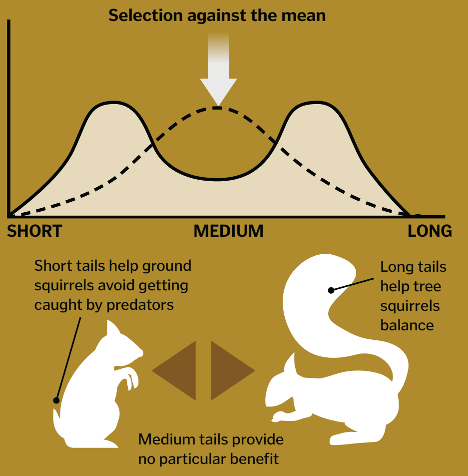
Stabilising

Stabilising selection encourages organisms to keep the same traits. This tends to happen when the environment is stable and the organism is already well adapted. Any changes make them less fit and therefore less likely to pass on their genes.



Disruptive

Sometimes there is more than one way to adapt to a change in the environment. In these situations organisms evolve away from the middle ground and towards one of two extremes. If this persists a population may split into two new species.



Sexual

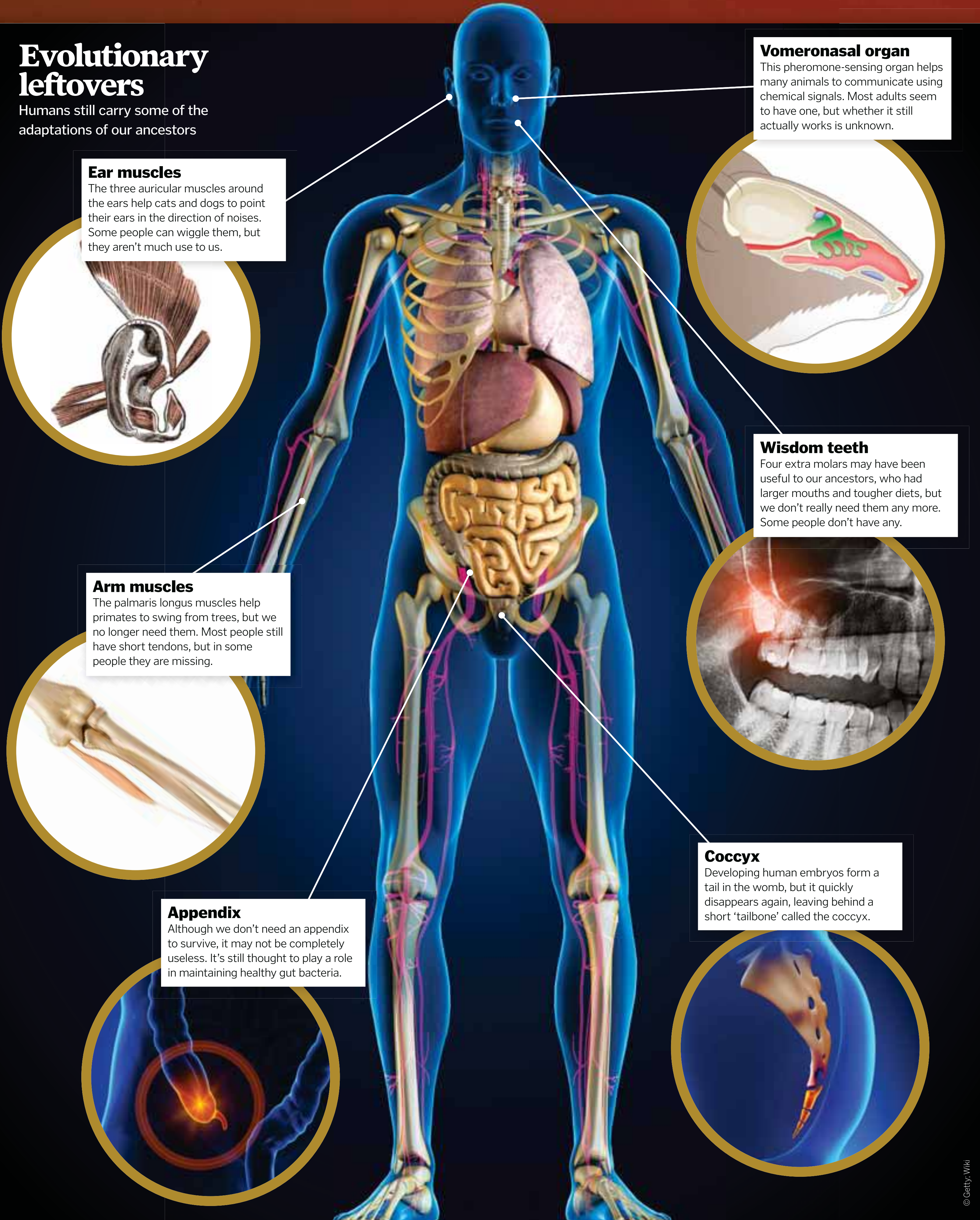
Natural selection favours animals best suited to their environment, but it's not the only way. Sexual selection favours traits that make individuals more attractive and more likely to reproduce, even if they don't help them to survive.

Artificial

Artificial selection works in the same way as natural selection, except that we make the decisions. By choosing which animals to breed, we dictate which traits are passed on to the next generation.

Evolutionary leftovers

Humans still carry some of the adaptations of our ancestors



Ear muscles

The three auricular muscles around the ears help cats and dogs to point their ears in the direction of noises. Some people can wiggle them, but they aren't much use to us.

Vomeronasal organ

This pheromone-sensing organ helps many animals to communicate using chemical signals. Most adults seem to have one, but whether it still actually works is unknown.

Wisdom teeth

Four extra molars may have been useful to our ancestors, who had larger mouths and tougher diets, but we don't really need them any more. Some people don't have any.

Arm muscles

The palmaris longus muscles help primates to swing from trees, but we no longer need them. Most people still have short tendons, but in some people they are missing.

Coccyx

Developing human embryos form a tail in the womb, but it quickly disappears again, leaving behind a short 'tailbone' called the coccyx.

Appendix

Although we don't need an appendix to survive, it may not be completely useless. It's still thought to play a role in maintaining healthy gut bacteria.

under blazing sunshine to survive, and body hair became a burden. Bare skin and the ability to lose heat by sweating became an advantage. Pressure from the environment pushed the genes of our ancestors to change.

Over time, early humans evolved bigger brains, smaller jaws and complex social structures. We harnessed fire and invented tools, and as we became more intelligent we made more and more changes to our environment. This changed everything.

The advent of agriculture around 10,000 years ago caused a seismic shift in human history. Suddenly, we could produce our own food on demand, right next to our homes. DNA from ancient humans has revealed that changing our own environment changed at least 12 regions of our genetic code.

Researchers at Harvard Medical School examined the remains of 230 people who lived between 8,500 and 2,300 years ago. They found differences in genes involved in height, metabolism and skin pigmentation. Around 4,000 years ago, a mutation appeared that allowed adults to keep digesting milk. Light skin became more common, which the researchers believe may have been a response to less vitamin D in a plant-based farmer's diet. The immune system also changed, which may have helped people to live closer together.

We share behaviours that we learn during our lifetimes, passing information from generation to generation like genes. Learning and culture change our environment, changing the pressures that drive selection. This kind of genetic and cultural co-evolution isn't unique to humans. Whales and dolphins are some of the most intelligent animals on the planet, and there is evidence that they also evolve in response to learning.

Killer whales can tackle many different types of prey, but certain groups prefer different meals. In the North Atlantic, for example, some like salmon, some prefer mammals, and others eat sharks. These cultural preferences pass from mother to baby, and because the groups don't tend to mix, they stay the same across generations. Scientists found differences in the genetics of whales that eat fish versus those that eat mammals. We changed our genes by learning to farm, and they've changed theirs by choosing which prey to eat.

This cultural learning helps us to keep adapting, but humans have taken it further than any other animal. We made clothes and complex shelters. We domesticated plants and animals to provide a steady source of food. We built boats, cars and planes to explore the world. We invented medicine to treat injuries and disease. We made it possible to choose when – and if – to have children. We can even survive in space. We have secured our environment, reducing the pressures that push other species to change over time. Reducing those pressures freed up even more time for new ideas and new technologies. Science has made it possible to change our environment more than ever before, but does that mean that we've stopped evolving?

It's hard to see evolution in action in human populations today because we have such a long lifespan, and even when natural selection isn't happening, our genes continue to mutate, a phenomenon known as genetic drift. However, there is one serious selective pressure that we still don't have under control: disease. If you look into its past you can see how modern humans have changed in recent years.

The plague ripped through Europe around 750 years ago, killing vast numbers of people. When our species faces diseases we can't yet treat, natural selection takes over. Scientists think that's why modern populations in Northern Europe have a higher frequency of a mutation in a gene called CCR5. This gene codes for a molecule used by the immune system, and it provides protection against the plague bacteria, *Yersinia pestis*. It also protects against the HIV

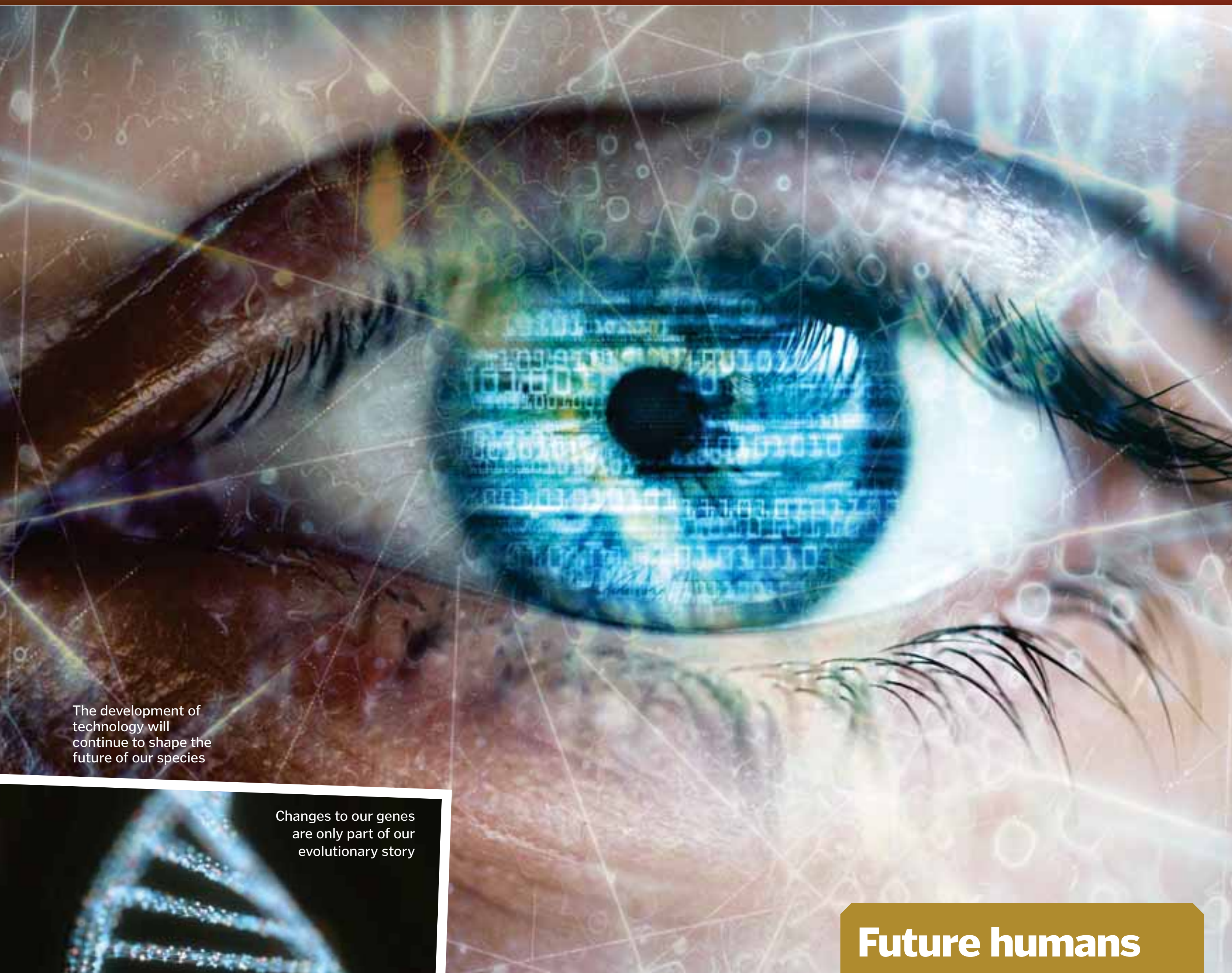
Ongoing evolution

Two recent studies have found evidence to suggest that we are indeed still evolving, albeit very slowly. Among smokers, those with a variant of a gene known as CHRNA3 are associated with smoking more heavily than average. Being a heavy smoker increases the risk of dying from a smoking-related disease, such as lung cancer. Scientists found that, between generations of 80-year-olds and 60-year-olds, the variant of this gene has decreased by about one per cent. However, until further data is collected from younger generations, this trend cannot be confirmed.

A similar decline seems to be emerging in those with a variant of the gene ApoE4, which increases the risk of developing late-onset Alzheimer's and cardiovascular disease. One possible explanation for both these gene variants becoming rarer is that more people are having children later. The number of people waiting until their 40s or 50s to start a family is increasing, but this is also the age at which people with such gene variants may be at risk of dying.

Smokers with a variation in the CHRNA3 gene are more likely to be heavy smokers

The jaws of humans and chimpanzees reflect our different diets



The development of technology will continue to shape the future of our species

Changes to our genes are only part of our evolutionary story

"Cultural learning helps us to keep adapting"

virus. People with the protective trait were more likely to survive, and their descendants are still alive today.

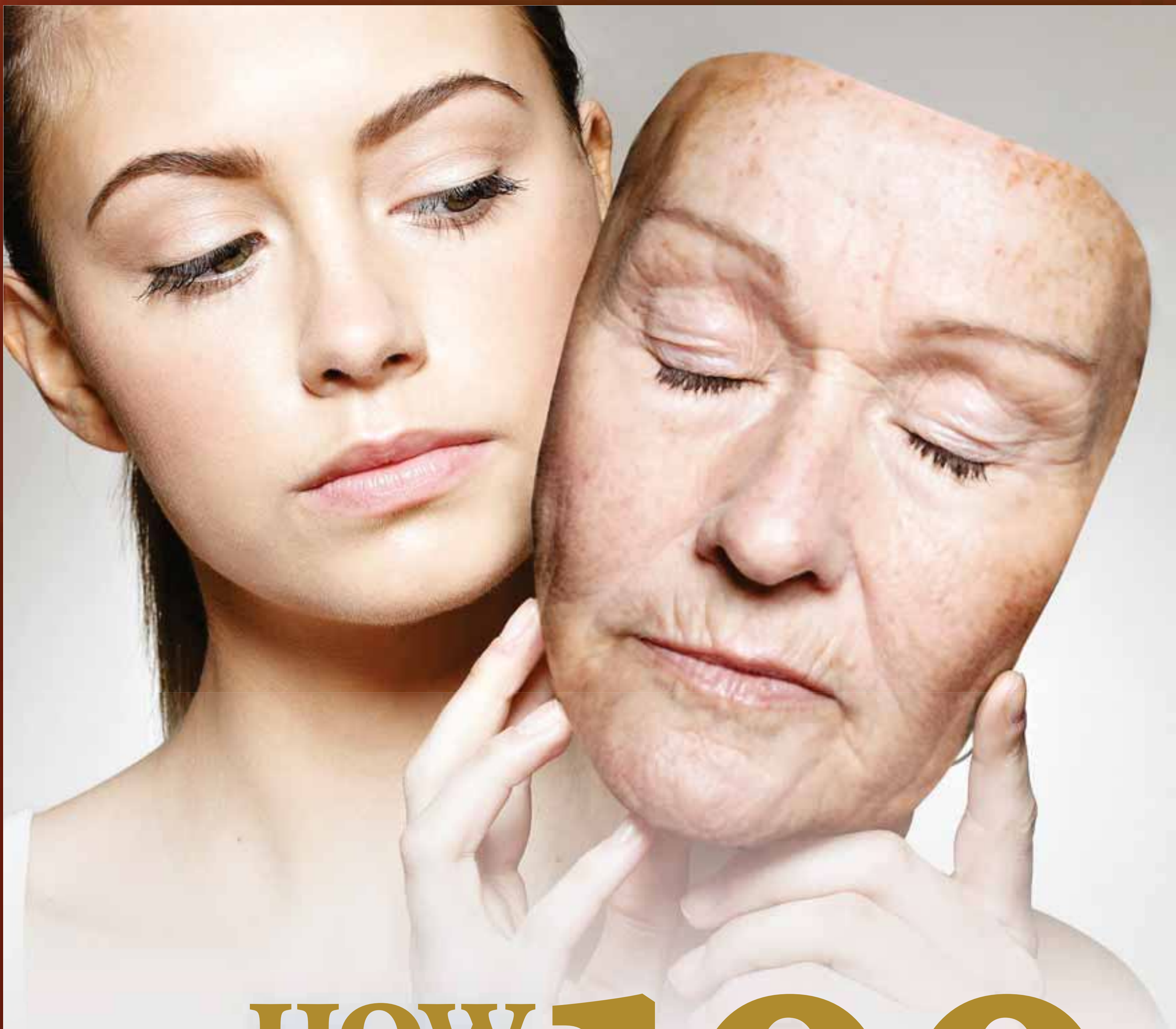
As a species we have outsourced huge parts of our survival to technology. We control our environment to maintain a steady state, reducing the pressure that forces genes to change, but to keep this going we need our environment to stay the same, and we haven't worked it all out yet.

What happens when the climate changes, or when antibiotics no longer work as they should? We have buffered ourselves against natural selection for the moment, but we haven't out-evolved evolution.

Future humans

Work is underway to extend our understanding of evolution beyond the ideas set out by Darwin. It's not just genetic inheritance that affects our evolution; the environment that our parents pass on changes us too. In new environments different genes become more or less useful to our survival. By changing our environment we change the selective pressures that drive our species forward. In biology this process is known as niche construction.

Data suggests that cultural evolution has already changed the way that our genes evolved by affecting the type of selection we are under. Even so, our genes don't always need to change for our species to adapt. We can change our environment much more rapidly than we change our genes, allowing us to thrive in situations that our biology couldn't handle alone. Computer simulations suggest that this kind of cultural evolution could work in a similar way to genetic evolution, only faster. Who knows where that will take us as human culture continues to change and technology continues to improve.



HOW TO LIVE BEYOND 100

What science can do to keep us looking and feeling younger

Words by **Laura Mears**

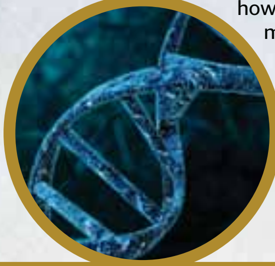
We are born, we live, we age and we die. This is the natural cycle of human existence, yet some people live longer than others. The world record holder for the longest human life is Jeanne Louise Calment of France, who lived to a magnificent 122 years and 164 days. But what is the secret to a long life? Human beings are complex, and we live for a very long time, making studies of the process of ageing a serious challenge. Most of the research to date has therefore been done in animals. Two of the favourite species for these kinds of studies are Caenorhabditis elegans, a tiny worm about the size of this comma, and Mus musculus, the humble laboratory mouse. The worms generally live for just two or three weeks, while the mice have an upper lifespan of around three years, and both have a lot of genes that are quite similar to our own. Using these models, researchers have identified several possible candidates, including stem cells, calorie restriction, and even some drugs, that could hold off the ageing process.

Scientists across the world have been trying to find the answers for decades, and after years of careful research, there is now a wealth of knowledge just waiting to be tested in people. We spoke to Brian Kennedy, CEO of the Buck Institute for Research on Aging: "We're a non-profit medical research institute that's focused on understanding ageing. We realised when the doors opened in 1999 that ageing was the biggest risk factor behind all of the disease that we care about," he explains.

"I think the exciting thing that we have learned over the past decade is that it's really possible to slow ageing in a mouse, or even in primates. The challenge now is to take that knowledge and apply it to humans. We're not just talking about lifespan, what we really want to do is to extend healthspan: the period of time that you're disease-free and functional. The field has amassed a whole load of candidates to slow ageing, and the challenge now is to figure out how to test them."

Why do we age?

There is no easy answer to this question. As with almost everything else in biology, it is a combination of genetics and environment. One of the most well-established theories about why we age is that it is an accident of evolution. Charles Darwin's famous theory explains that the 'fittest' or best-adapted animals will reproduce, passing on their genes to the next generation. To get this chance, they need to be able to survive through their early years, find a mate, and help their young to make it to adulthood. Over the course of our lifetimes, our bodies take damage and start to deteriorate, but after reproduction, it doesn't matter so much how long animals live. There is therefore much less pressure to evolve genes that extend life and reverse the damage. In fact, it might even be better in evolutionary terms to live fast and die young, if it means that you have a better chance of passing on your genes.



What makes us age?

There are several different factors thought to contribute to the ageing process

Calories
This is one of the most established areas of research. In mice, rats and even primates, limiting food intake to the minimum requirement extends lifespan.

Damage
Over time, our DNA starts to accumulate mistakes. This is due to damage from the environment as well as errors made when our cells divide.

Stem cells
Stem cells can reproduce to replace cells that are damaged or worn out. As we age, they become less able to function, slowing the rate of repair.

Inflammation
Chronic inflammation is found in many age-related diseases, even when there is no infection to fight, but the relationship with aging is unclear.

Telomeres
The ends of our chromosomes are capped with stretches of protective DNA called telomeres. Every time a cell divides, part of this cap is lost.

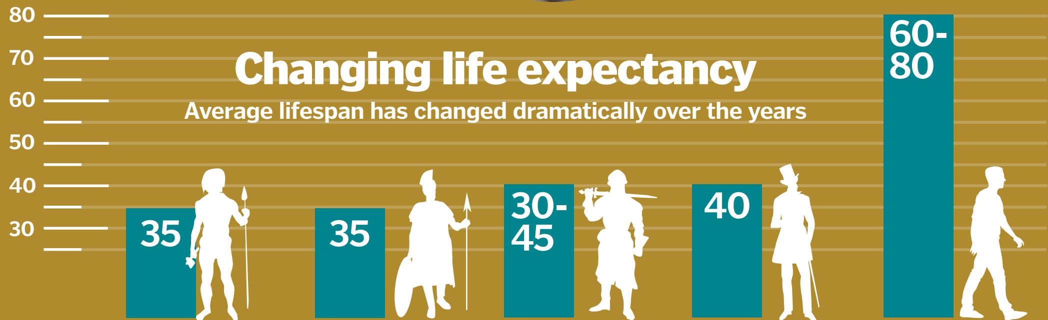
Glycation
Molecules called 'advanced glycation end products', or AGEs, form in our bodies over time. They have been implicated in several age-related diseases.

Do we have an age limit?

In 2010, an estimated eight per cent of the world's population were over the age of 65. By 2050, this is expected to rise to 16 per cent – that's around 1.5 billion people. But despite this seemingly phenomenal increase in human lifespan, there has actually been little change in the upper limit of human age over the last 2,000 years. Some people were living into their seventies back then, too. Brian Kennedy says: "Median life expectancy has been going up at a pretty high rate. But that's median life expectancy. The question of whether we can extend the maximum is still a bit open."

Changing life expectancy

Average lifespan has changed dramatically over the years



Prehistoric
Some prehistoric humans lived into old age, but the majority died young.

Classical antiquity
Some Ancient Greeks and Romans lived into their 70s and beyond.

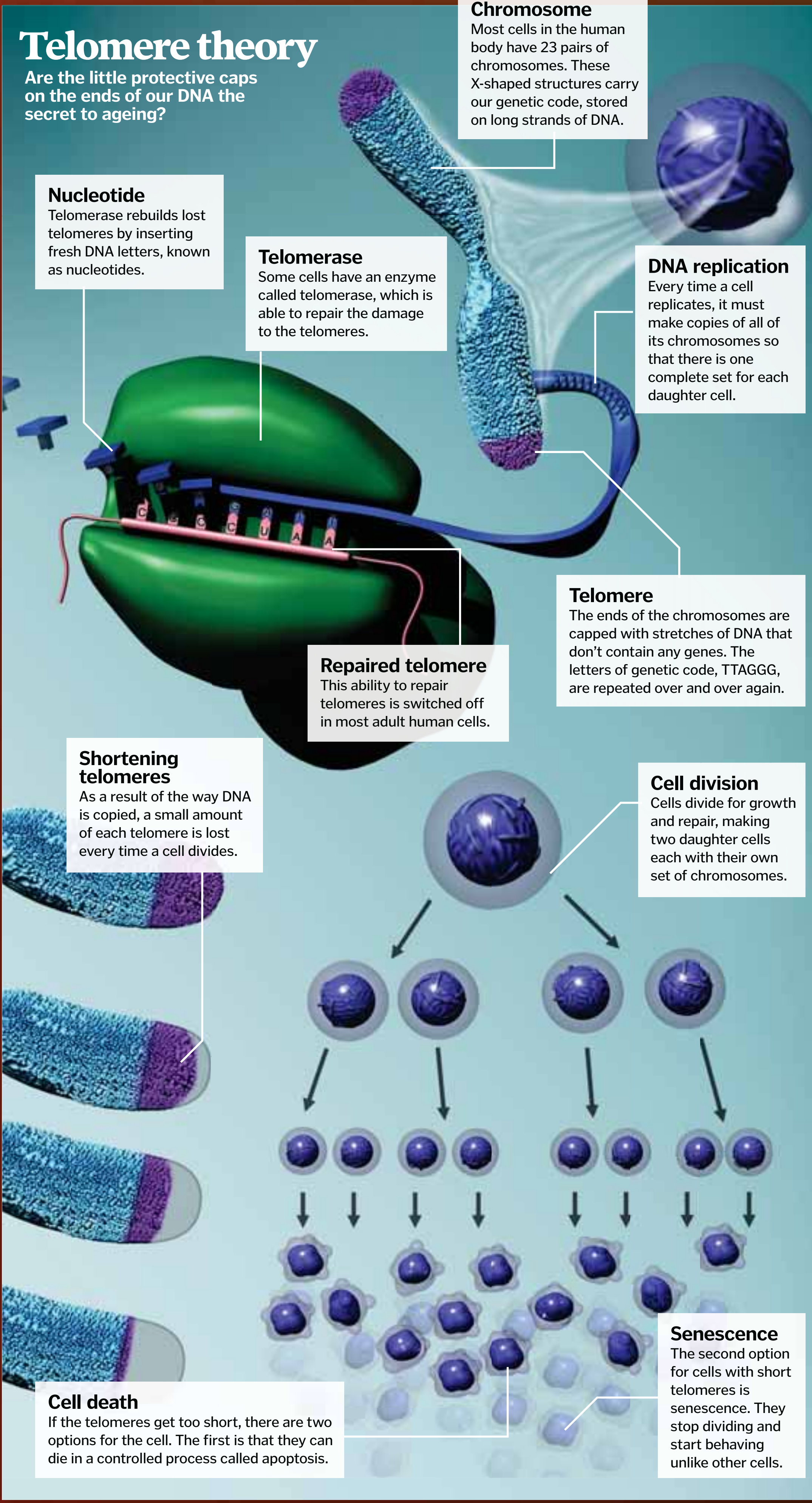
Medieval
Surviving childhood and childbirth were both major challenges.

Victorian
At this time, three in ten babies died before they reached their first birthday.

Today
Life expectancy varies across the world, and is highest in developed countries.

Telomere theory

Are the little protective caps on the ends of our DNA the secret to ageing?



Chromosome
Most cells in the human body have 23 pairs of chromosomes. These X-shaped structures carry our genetic code, stored on long strands of DNA.

Nucleotide
Telomerase rebuilds lost telomeres by inserting fresh DNA letters, known as nucleotides.

Telomerase
Some cells have an enzyme called telomerase, which is able to repair the damage to the telomeres.

DNA replication
Every time a cell replicates, it must make copies of all of its chromosomes so that there is one complete set for each daughter cell.

Telomere
The ends of the chromosomes are capped with stretches of DNA that don't contain any genes. The letters of genetic code, TTAGGG, are repeated over and over again.

Repaired telomere
This ability to repair telomeres is switched off in most adult human cells.

Shortening telomeres
As a result of the way DNA is copied, a small amount of each telomere is lost every time a cell divides.

Cell division
Cells divide for growth and repair, making two daughter cells each with their own set of chromosomes.

Senescence
The second option for cells with short telomeres is senescence. They stop dividing and start behaving unlike other cells.

Cell death
If the telomeres get too short, there are two options for the cell. The first is that they can die in a controlled process called apoptosis.

Slowing the body clock

The latest research aims to put the brakes on ageing and extend healthy years of life

Almost all of our cells have 23 pairs of chromosomes. Each chromosome contains a long molecule of DNA, wound around a series of proteins to form an X-shape, and the ends are capped with structures known as telomeres. These have been a focus for anti-ageing researchers for many years because every time a cell divides, they get a little bit shorter. Eventually, the telomere is so small that the cell can no longer go on dividing.

As Professor Kennedy explains, "If you take cells out of the body and grow them in the test tube, it was found out many years ago that eventually they stop growing. People have thought for 50 years now that this may be a component of ageing." Telomeres can be lengthened again by an enzyme called telomerase, which is found in some stem cells. However, in most adult cells, telomerase is switched off. Without it, telomeres gradually get shorter as we get older, and our cells start to shut down. Some of these older cells die, while others just stop dividing and become 'senescent', which literally means 'to grow old'.

Researchers at the Buck Institute are very interested in senescence. "One of our investigators, Judy Campisi, has been developing strategies to get rid of senescent cells in the body," he continues. "The problem has always been that there aren't that many senescent cells in the body, even in older people. It might be five per cent of the tissue, ten per cent of the tissue." So the argument was always, 'How can that have that big of an effect if it's only a small proportion of the tissue?' What Judy has found is that these senescent cells secrete factors that have bad effects on the cells in their environment."

Dr Campisi focused first on investigating the process in mice, and has developed a way to kill the senescent cells using genetic engineering. "When you do that, the animals stay healthy longer," Kennedy explains. Dr Campisi is now working on finding a drug that can produce the same results. But the aim isn't necessarily to extend life. These senescent cells could be contributing to age-related diseases, and that's the real focus for the researchers. "Our goal is to keep people healthy and functional longer. They will probably live longer too, but it's really about healthspan more than lifespan".

Anti-ageing pills

A pill to slow the ageing process might sound inconceivable, but there are actually a few candidate drugs already. Two of the most publicised are rapamycin and metformin. It has been known for a long time that restricting calorie intake can extend the lifespan of mice, and researchers have pinpointed genes involved in a nutrient-sensing pathway called 'target-of-rapamycin' (TOR). When cells have lots of nutrients, this pathway promotes growth, but when nutrients are scarce, it switches the cell over to recycling its own molecules. This switch seems to be critical.

Rapamycin is a drug already used in people to prevent the rejection of transplanted organs, and it dampens the activity of the TOR pathway, helping cells to switch into recycling mode. Rapamycin slows ageing in worms, flies and in mice, but the effects on humans aren't yet known.

An alternative anti-ageing candidate is metformin. This drug decreases the amount of glucose made by the liver and increases uptake of glucose from the blood, and is already used to treat diabetes. Evidence in worms and some mice shows that metformin can increase longevity, and it also seems to decrease the risk of age-related diseases in people with diabetes. It is not clear whether the drug would have any benefit in healthy people, but researchers in the United States are keen to do a clinical trial to find out.

Human studies are needed to find out whether these drugs really can slow ageing

The future of anti-ageing

At the moment, most anti-ageing research is focused on extending human healthspan by staving off disease. But we are in the midst of a scientific revolution, and there is no telling what will be available hundreds of years from now. Already, scientists can build bionic limbs that respond to the wearer's thoughts, they're learning the incredible potential of stem cells, and they can 3D print structures for transplanting into the body. In the future, some hope that it will be possible to go beyond biology, using these kinds of advances to become 'transhuman' – living longer, and ultimately cheating death completely.

The ideas for transhumanism are limitless, and range from augmented body parts, through to genetic modification and cloning, all the way up to downloading your thoughts onto a memory stick and living forever as a machine. Unfortunately – or fortunately, depending on how you look at it – this future is still a long way off.

"Our goal is to keep people healthy and functional longer. It's really about healthspan more than lifespan"
Brian Kennedy

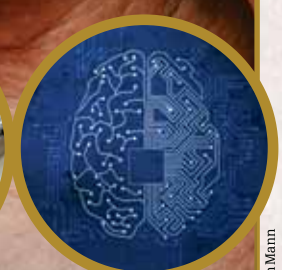
Elixir of youth
Drugs may one day be able to slow the ageing process, and help to avoid diseases like Alzheimer's or Parkinson's.

Genetic engineering
Editing the youthfulness genes in our genome could change the way that humans age.

Cloning
How about living again as an identical version of yourself? Cloning technology could make copies of you or your cells.

Upgrading organs
Advanced 3D printing techniques could lead to custom-made organ replacements.

Replacing limbs
Bionic limbs have the potential to be stronger and more durable than the real things.



Downloading your brain
Will it ever be possible to replicate the most complex structure in the known universe?

WELCOME TO THE HUMAN AGE

Have the changes we are making to the planet ushered in a new geological epoch?

Words by **Joanna Stass**

The planet we call home has been around for 4.6 billion years, and a lot has changed in that time. Continents have drifted, climates have fluctuated, species have come and gone and, of course, humans have evolved. All of these milestones are well documented in changes in the fossils and chemical signals found in Earth's layers of rock, and this has enabled geologists to divide the planet's timeline into several distinct eras.

You are probably familiar with the Triassic, Jurassic and Cretaceous periods in which the dinosaurs lived, but today we live in what has been officially labelled the Holocene, a name that comes from the Ancient Greek for 'entirely recent'. This epoch began 11,700 years ago after the last major ice age and, for the most part, has featured a relatively stable climate. This has enabled us to plan ahead and greatly improve our way of life by inventing agriculture, harnessing new forms of energy and building cities.

However, some scientists are now arguing that the enormous impact all of this human activity has had on the planet has led us into an entirely new geological epoch: the Anthropocene. This term, which roughly translated from Greek means 'the age of humans', was first coined in 2000 by the Dutch Nobel Laureate chemist Paul Crutzen. Recalling the moment he first came up with the name, Crutzen said, "I was at a conference where someone said something about the Holocene. I suddenly thought this was wrong. The world has changed too much. No, we are in the Anthropocene. I just made up the word on the spur of the moment. Everyone was shocked. But it seems to have stuck."

Indeed, the term has grown in popularity with scientists ever since, having appeared in nearly 200 peer-reviewed journals and even inspiring the name of a brand new academic journal: *Anthropocene*. Nevertheless, it is still not recognised as an official epoch. For that to happen, the International Union of Geological Sciences (IUGS), the professional organisation in charge of defining Earth's time scale, must declare it so. In 2016, the Working Group on the Anthropocene (WGA) voted to formally recognise the new epoch and presented its case to the International Geological Congress, but a final decision has not yet been reached.

In the past, such a decision has taken decades and even centuries to make, as to identify the boundary between distinct eras there must be enough evidence of a signal that occurs globally between layers of rock. For example, the end of the Cretaceous period was identified by a 'golden spike' of the metal iridium that was dispersed in sediments around the world by the asteroid that wiped out the dinosaurs.

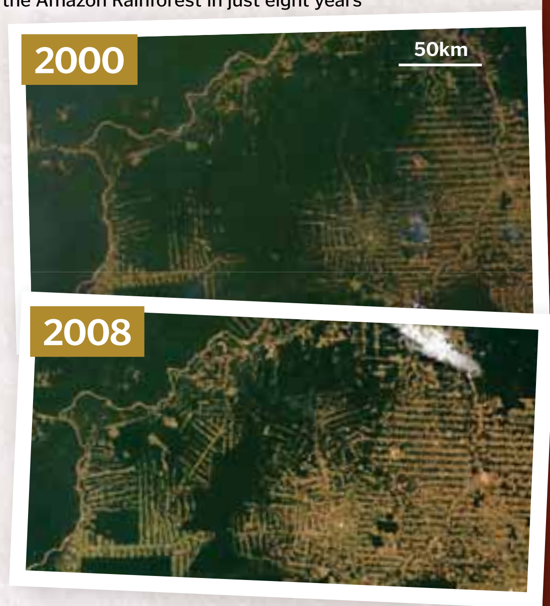
Although it is hoped that the Anthropocene could be declared in the next few years, the main problem geologists face is working out exactly when it began. Some argue that it happened thousands of years ago with one of the biggest human led changes: the invention of agriculture.

However, the crops grown by our early ancestors did not have a great deal of impact on the Earth's rock, and the development of new farming practices was relatively gradual. Therefore, another of the more popular arguments puts the date at around 1750 when the Industrial Revolution took hold. At this time the use of fossil fuels led to a significant rise in the amount of carbon dioxide present in the atmosphere, and mining for coal, oil and gas also drastically altered the landscape.

"Some have suggested the 1950s as the greatest turning point in our impact on the Earth"

Alternatively, some have suggested the 1950s as the greatest turning point in our impact on the Earth. At the end of the Second World War, old economic institutions began to break down and the world became increasingly more connected. The human population began to grow at an incredible speed, an event scientists commonly refer to as the Great Acceleration, and the nuclear age began to dawn. Some believe that it will be the radioactive signatures deposited into the

These images highlight the levels of deforestation in the Amazon Rainforest in just eight years



Earth from these first atom bomb tests that will help future geologists define the start of the Anthropocene, while others suggest it could be plastic pollution, the soot from power stations or the concrete used for infrastructure. Even the domestic chicken could become the crucial marker, as thanks to our desire for meat and eggs, it has now become the most common bird in the world.

While this more recent date is considered by many to have the most merit, some geologists argue that there is still not enough clear-cut evidence to define the end of the Holocene. Nevertheless, whether there is a physical boundary to be found or not, there is no denying that humans have had a lasting impact on the environment. We may have only existed on Earth for less than 0.01 per cent of its history, but in that time we have irreversibly reshaped the planet far faster than natural geological processes would have done. In fact, more change has occurred in the past century than in the previous 250,000 years of human history, and we show no sign of slowing down.

Of course, not all of the changes we have made have been negative. The massive explosion of innovation and discovery in recent years means that most of us now experience a much better standard of living than our ancestors did. Manufacturing jobs have lifted millions of people out of poverty, freeing them from the cycles of starvation and famine that comes from relying on an income from agriculture. Modern technologies can also feed and clothe more people than ever before, as machinery and automation simultaneously speed up and reduce the costs of manufacturing techniques.

Advancements in medicine, such as the development of vaccines and genetic engineering for the development of drugs and gene therapies, have also significantly lowered the death rate, while economic development is helping to reduce the need for larger families and slow population growth. We also know more about our planet and the universe than ever before, enabling us to learn from its history, understand its present and plan for its future.

"The plants and animals we have no use for are becoming extinct at an alarming rate"

Nevertheless, our quest for better lives has not benefited everyone equally. While overall standards of living are improving, the wealth inequality gap is getting wider as more people in the developing world are forced into low-paying jobs that produce goods for developed countries. Using current modes of production, we can only support a population of two or three billion people who enjoy the same standard of living as those in the United States, yet the global population has risen from 1 billion to over 7 billion since the 1800s.

This is also compounding our impact on the environment. The space needed to accommodate and fuel the growing population has led us to alter more than 50 per cent of the Earth's land by clearing forests, building cities and damming rivers. There are now half as many trees as there were before human's existed, and all of this is resulting in a massive reduction in biodiversity across the globe. The

It is estimated that 60 per cent of the global population will live in urban areas by 2030

Some geologists believe the Anthropocene began on 16 July 1945, the day of the first atomic bomb detonation

Plastics take thousands of years to degrade and may prove to be a signature of the Anthropocene

In 2015, delegates from nearly 200 countries signed the Paris Agreement, pledging to take more action to combat humanity's effects on climate change

plants and animals we have no use for are becoming extinct at an alarming rate, 100- to 1,000-times faster than if we had no input, and this is set to increase further in the coming years. Many scientists argue that is the strongest argument for declaring a new geological era, as when future geologists study the fossil records of this time period, they will see a mass extinction event on par with the five most devastating extinction events in Earth's history, including that which wiped out the dinosaurs.

Another major environmental impact is that of climate change. Since 1750, there has been a sharp increase in the amount of greenhouse gas released into the atmosphere, including carbon dioxide from burning fossil fuels, nitrous oxide from the use of fertilisers and methane from livestock and landfill. This has caused a thinning of the ozone, a protective layer in the atmosphere that filters out harmful ultraviolet radiation from the Sun, which is changing the climate at a faster rate than has ever been recorded. The dramatic increase in surface temperature is accelerating the melting of the Greenland and West Antarctic ice caps, which is likely to cause a more than five-metre rise in global sea levels over the coming centuries. This will cause low-lying coastal areas to flood, diminishing the amount of land available for our growing numbers to farm and live on.

Coastal regions are also being negatively affected by the increase in the use of artificial nitrogen-based fertilisers necessary for industrialised agriculture. As farmers inevitably use more of these chemicals than they actually need, any excess finds its way into waterways and heads for the shores. There it feeds plankton blooms, which can suffocate fish and shellfish, causing vast dead zones where coastal life cannot survive.

By studying all of these changes, scientists have gathered overwhelming evidence that they are being caused by human activity. Most graphs tracking such things as greenhouse gas concentrations, extinction rates and

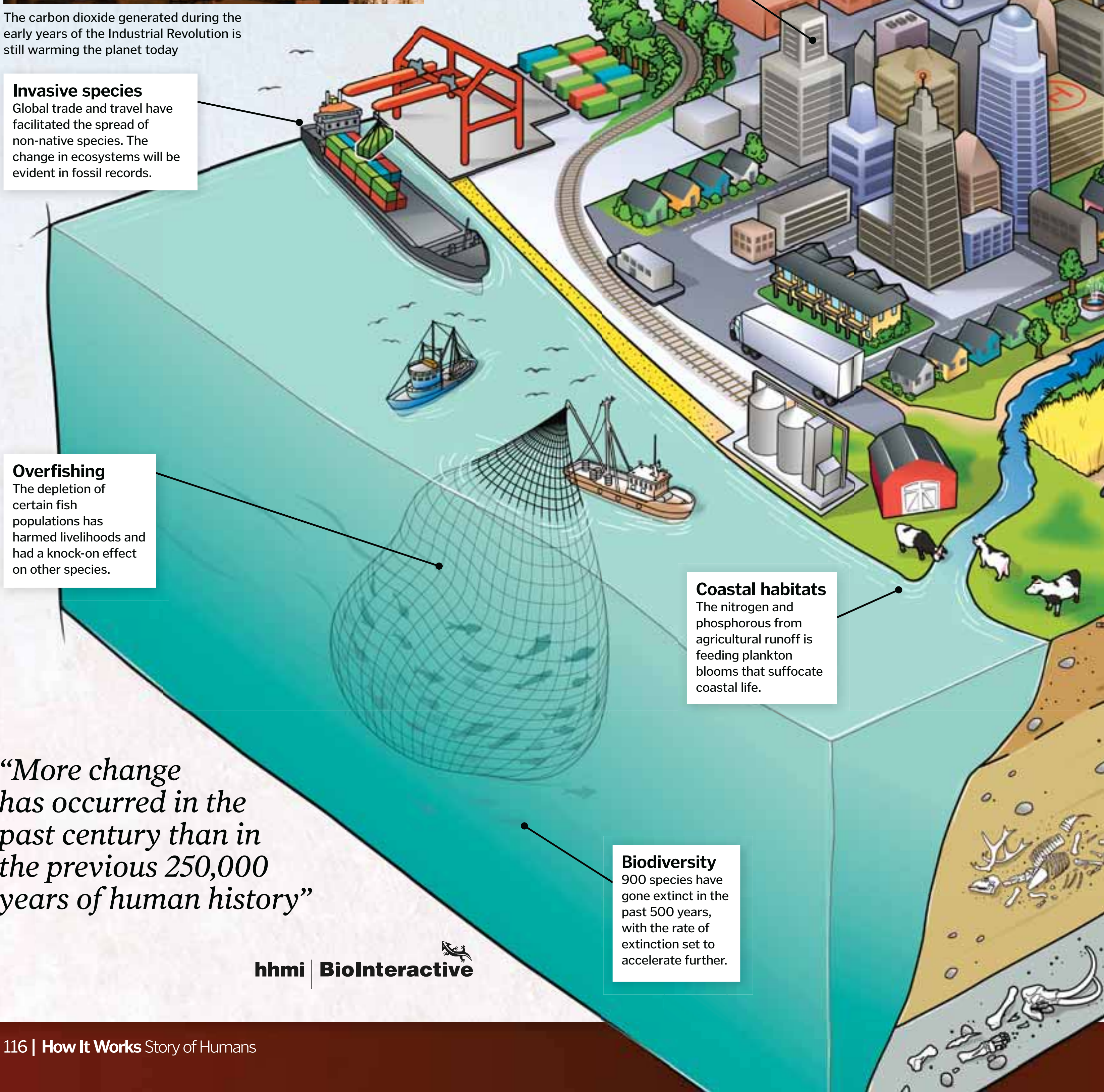
The rising urban population

How are the world's biggest megacities set to change in the next few decades?

The carbon dioxide generated during the early years of the Industrial Revolution is still warming the planet today

The human impact

What evidence might future geologists use to define the Anthropocene?



"More change has occurred in the past century than in the previous 250,000 years of human history"

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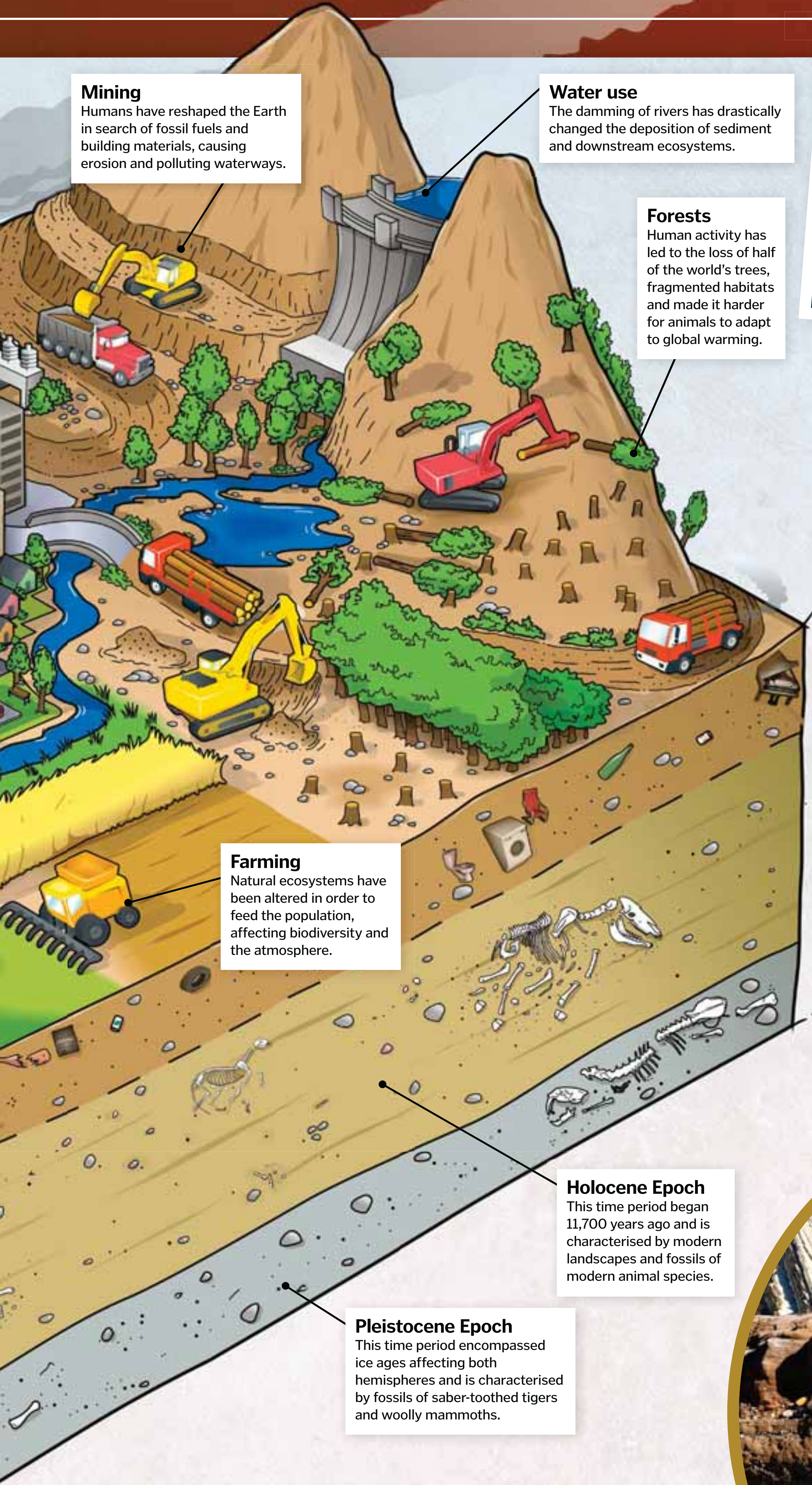
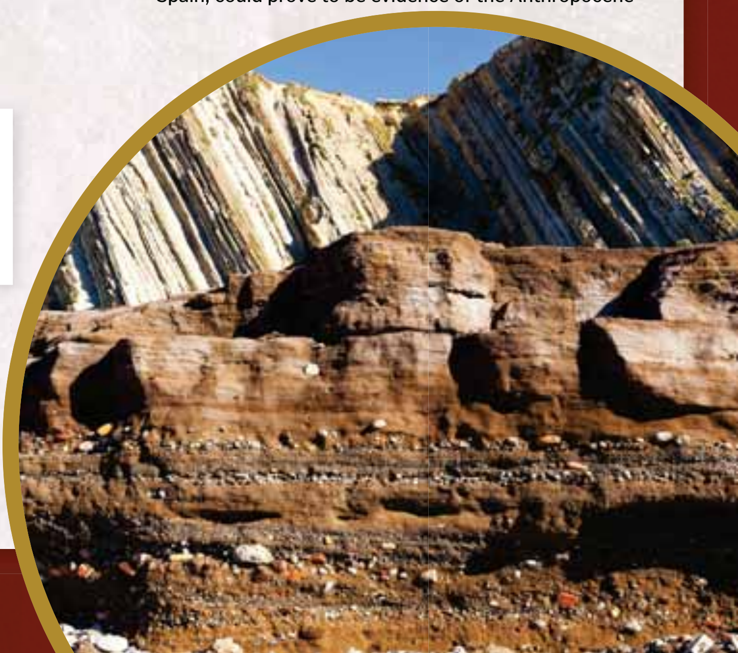
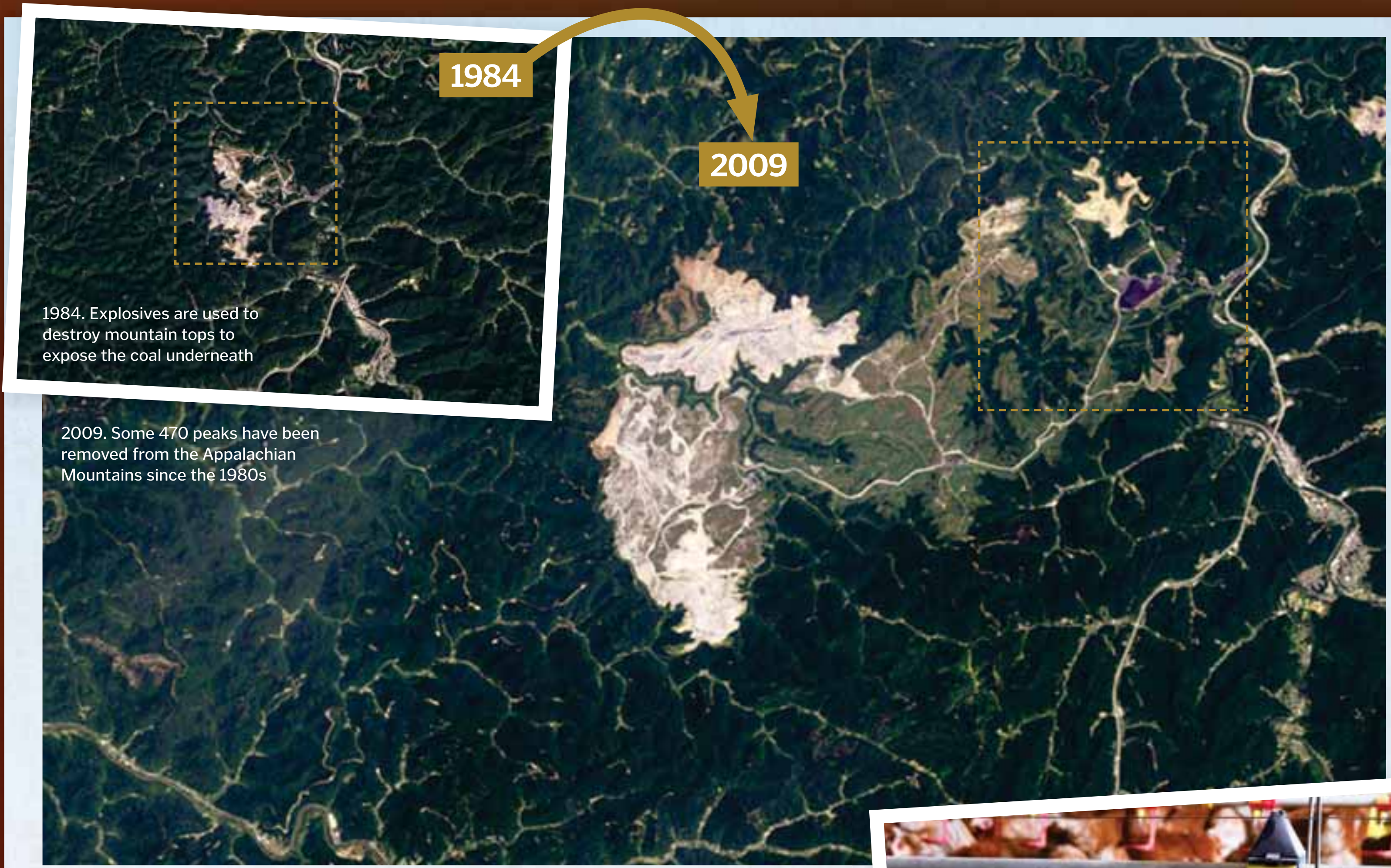


Just a few decades ago Dubai was mostly desert, but today it is one of the fastest-growing cities in the world

Below: a 7m layer of industrial sediment deposits in Biscay, Spain, could prove to be evidence of the Anthropocene





1984. Explosives are used to destroy mountain tops to expose the coal underneath

2009. Some 470 peaks have been removed from the Appalachian Mountains since the 1980s

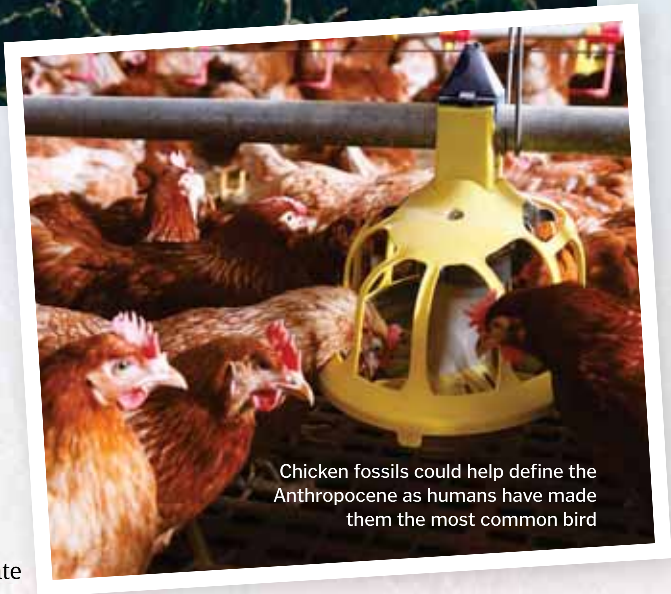
deforestation show a sudden steep climb following the year 1950 when the Great Acceleration began. However, as history has shown us, these kinds of changes are not unprecedented. The climate, biodiversity and geology of the Earth have all been drastically altered before, creating conditions far hotter and colder than the current global average. So what is it that makes the shift into the Anthropocene any different?

For the first time in the Earth's history, one species alone is causing all of these changes to the planet. And what's more, we know we are doing it. This is one reason why many geologists are so passionate about officially declaring the Anthropocene. Normally naming a new epoch is a matter of formality, but it is hoped that this time it could help to change people's view of the relationship between humans and the Earth.

By actively acknowledging that we are having such an enormous impact on the environment, we have the power to determine what its future will look like. At the moment, there are several possible scenarios that could play out, and it is up to us to decide which one to choose. Of course, we could simply carry on as we are, but that will only increase the likelihood of some pretty catastrophic events occurring. In the next century, the global population is set to grow to between 10 and 12 billion people, where it will hopefully level off due to declining birth rates. We are already struggling to provide 7 billion people with a decent standard of living, and so at our current rate of consumption, supporting even more is going to be a major challenge. Overpopulation could spark global conflicts and lead to a rise in instability, all of which would be made worse by the effects of global warming.

"In the next century, the global population is set to grow to between 10 and 12 billion people"

The climate is already changing at an alarming speed, but providing enough fuel for 10 to 12 billion people will only accelerate these changes even more if we continue to use coal, oil and gas. The global average temperature has already increased by one degree Celsius since the late 1800s, and just one degree more would produce some drastic results. Environmental disasters such as floods, droughts and hurricanes would become more common, temperatures would soar to uninhabitable levels and rising sea levels would submerge more and more land underwater. Future geologists, if they still exist, would be able to study the relics of our cities in amazing detail as they would be buried in mud deposited by the rising waters. Plus, not only would we struggle to adapt to this warmer, wetter world, but most animal and plant species would also not be able to evolve fast enough to survive in their new habitats.



Chicken fossils could help define the Anthropocene as humans have made them the most common bird

Another possible scenario would be to try to guide human society back to the simpler, subsistence living of the 1800s. This would involve each family building their own home,

The development and intensification of agriculture has led to huge changes in the natural landscape

Human activity and climate change are destroying delicate ecosystems such as those found on coral reefs

making their own clothes and growing their own food. It would also mean harnessing all of our power from renewable sources such as the Sun and wind and giving up modern technologies including cars and the internet. Although this would certainly reduce our impact on the environment, it is likely to be both unrealistic and unpopular with the current population. For a start, there's seven times the number of people there were in the 1800s who would need to be supported by this lifestyle, and many have already grown attached to the luxuries of modern life.

Therefore, the most likely way we will reshape the future is by inventing new technologies and implementing new processes to solve the world's problems. The fact that we are becoming increasingly well-educated and interconnected can only help with this, and there are already signs that attitudes are beginning to change. Innovations in clean energy and the development of electric cars are helping to reduce our dependence on non-renewable fossil fuels, and in 2015, nearly 200 countries pledged to do their bit in helping to tackle climate change by adopting the Paris climate accord.

This agreement sets out to limit the increase in the global average temperature to well below two degrees Celsius above pre-industrial levels and provides incentives to cap the amount of greenhouse gas emitted by human activity. Meanwhile, the decline in biodiversity is being tackled by conservationists around the world who are working to restore depleted habitats and protect species on the brink of extinction.

Even though changes are already being made, there is still a lot of work to be done if we want to reverse the damage we have caused to the planet and secure a more stable future. If we can't reduce the risks then there may be only one solution: leave this planet in search of another. Space agencies and private companies are already beginning to explore the possibility of establishing human colonies on Mars, with the first manned mission to the Red Planet currently scheduled for the 2030s.

The quagga, a subspecies of zebra, is one of the many animals humans have driven to extinction

However, while we are still a long way off being able to make other worlds habitable, it makes sense to do everything we can to save the one we know can support us. Even though the gasses we have already pumped into the atmosphere will last for tens of thousands of years, it's not too late to intervene. Using our collective intelligence we can work together to come up with viable solutions for halting greenhouse gas emissions, removing existing gasses from the skies and reversing the damage caused to crucial habitats. If we are indeed living in the Anthropocene, then it's up to us to make it the era that humans change the planet for the better, rather than making it worse.

The human effect in numbers

208

new minerals have been formed solely or primarily due to human activity

Earth's population is predicted to reach

9.8 bn

by 2050 - an increase of over

32%

compared to today's numbers

Some studies suggest human activity is causing species to go extinct

1,000

times faster than would occur naturally

The global population only surpassed

1 billion

for the first time in the early

1800s

More than half the concrete ever used was produced in the past

20 years

Agricultural space takes up approximately

37.5%

of global land area

200+

scientific articles about the Anthopocene were published in 2016 alone

HOW TO SAVE THE WORLD

Discover the incredible science and tech that will protect our planet

Words by **Luis Villazon**

8 million tons
The amount of plastic waste that enters the ocean each year

1 trillion
The number of plastic bags used each year worldwide

100 kilograms
The average amount of food thrown away every year per person in the UK – over half of which is perfectly edible!

100,000
The number of marine mammal deaths caused by plastic debris each year

90%
Proportion of the world's seabirds estimated to have ingested plastic, including bags and bottle tops

75,000
The number of trees that would be saved by recycling just a single run of the Sunday *New York Times*

15-30%
The proportion of childhood asthma cases that are thought to be triggered by air pollution

Can we stop global warming?

While governments squabble over carbon emissions, innovative technology could help to slow temperature rises

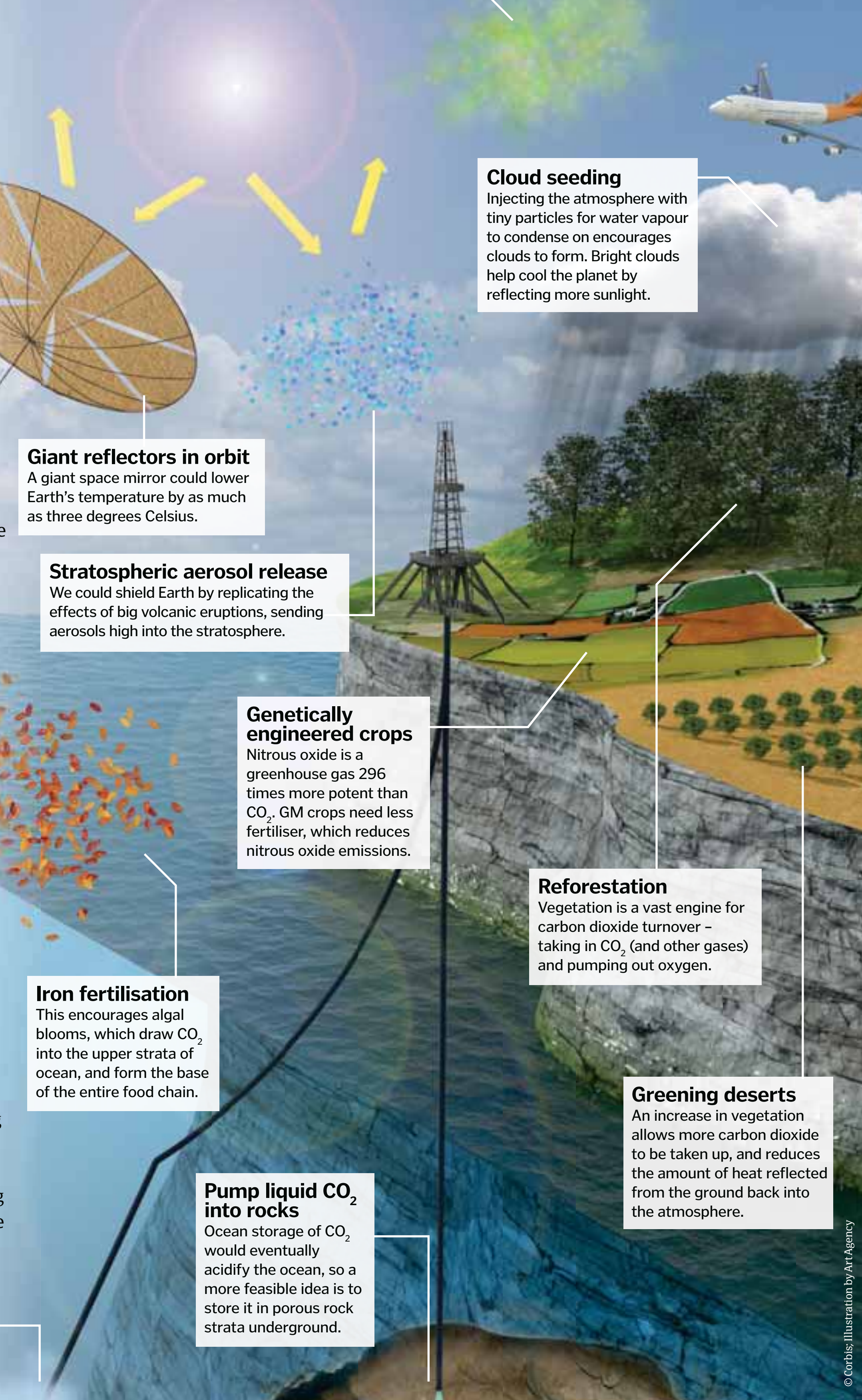
Humans only make up about one ten thousandth of the biomass on Earth, but our impact on the planet is drastically out of proportion to our numbers. In the last 250 years we have added over 400 billion tons of carbon to the atmosphere and approximately half of that has happened since the mid-1980s. No other organism in Earth's history has altered the environment so much so quickly.

It's not just the amount of pollution we produce either; humans have invented entirely new kinds of pollution too. Polythene, chlorofluorocarbons, organophosphates and synthetic hormones didn't exist in the environment until humans created them. Other toxins, like heavy metals and radioactive isotopes, were only there in trace amounts until the industrial age found new ways to refine and concentrate them. These pollutants are toxic because they are too new for life to have evolved a way of dealing with them, which means they don't get broken down either.

A 2007 study found more than 24 synthetic chemicals and pesticides in wild salmon – and non-toxic pollutants can be just as harmful. Fertilisers that run off the land into rivers can cause such a sudden explosion of algae that waterways are blocked with green slime. When this dies and decays, the surge in bacteria depletes the water of oxygen and kills off the fish.

But pollution is entirely within our power to control. In 1952, the Great Smog of London killed an estimated 12,000 people over four days, but four years later the Clean Air Act was passed and air quality steadily improved. The countries that were once the biggest polluters have also been the first to introduce emissions standards. Just 50 years ago, New York City was plagued by a dense smog responsible for around 24 deaths per day, but air pollution legislation and incentives have helped to drastically improve the city's air quality. The Big Apple is even working towards achieving the cleanest air of any major US city by the year 2030.

The technological progress that created the pollution can also be harnessed to curb it. Cleaner fuels, more efficient engines, better recycling, and environmental clean-up technologies are all being developed to slow the rate at which humans are poisoning the planet. From huge, garbage-sucking machines in the ocean to neighbourhood recycling schemes, there is a way for everyone to help ensure that Earth's most polluted century is behind us.



Land pollution

The toxic chemicals lurking beneath the surface of our poisoned planet


Waste from construction sites can be recycled at specialised plants

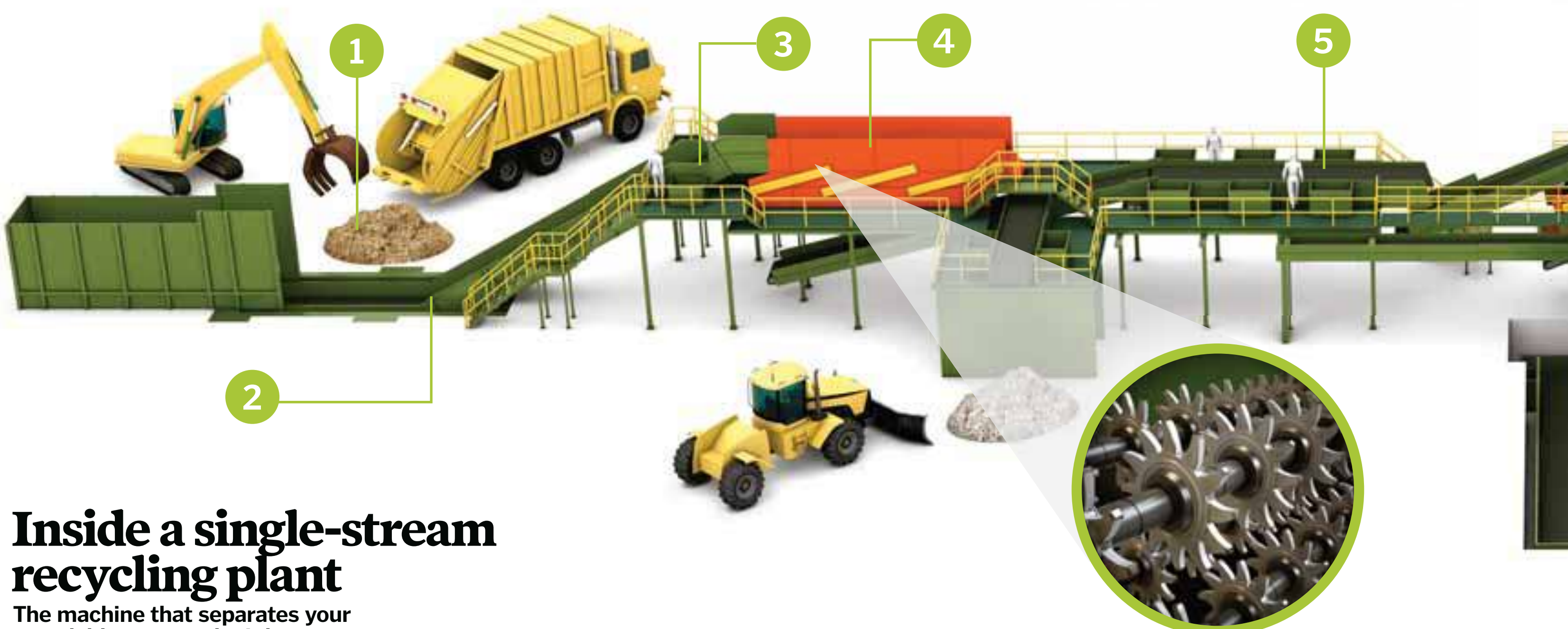
Land pollution isn't just about the space taken up by landfill. A city the size of New York could fit all of its rubbish for the next thousand years in a landfill 56 kilometres long by 56 kilometres wide. That sounds like a lot, but that's the waste of 2.5 per cent of Americans buried in just 0.03 per cent of the country's land area. And that land isn't gone forever – eventually a landfill site just becomes a grassy hill.

The real source of land pollution is all the other things that don't end up in landfill. Copper and aluminium mining generate huge piles of powdered rock (called 'tailings') left behind after the metal has been extracted. These tailings are high in toxic heavy metals, such as mercury and cadmium, and aluminium mining alone generates 77 million tons of tailings worldwide every year.

Modern farming also requires more than just sunshine and rain. In the UK, farmers add an average of 100 kilograms of nitrogen fertiliser to every hectare of arable land and grassland each year. Whatever the crops don't absorb gets washed into the groundwater and ends up in our rivers, going from land to water pollution.

The low-tech solutions to land pollution are the three Rs: reduce, reuse, recycle, and these are in decreasing order of effectiveness. Reducing the amount of cardboard or cabbage you need to buy in the first place has a much bigger impact than simply recycling all the leftovers, because it also saves the energy that would have been required to process and transport them to you, and then collect and recycle them again afterwards.

But there are high-tech pollution solutions as well. Bioremediation uses selected strains of naturally occurring organisms to break down contaminants in the soil. Wood fungi for example have been shown to break down the toxins in oil spills and also certain chlorine pesticides. Heavy metals like cadmium and lead can't be broken down, but certain plants will take them up through their roots and store them in their leaves or stems. This technique, which is known as phytoremediation, uses plants to soak pollutants from the ground so that they can be removed more easily. Chinese brake fern can even filter out arsenic in this way.



Inside a single-stream recycling plant

The machine that separates your recyclables so you don't have to

1 Tipping floor A steady stream of recycling collection vehicles arrives at the facility, dumping their cargo of mixed recyclables out onto the tipping floor. Drivers look out for any oversized objects like car engines that would cause damage to the plant machines.

2 Loading Powerful loaders shunt piles of assorted recyclables into a large hopper, where they are tumbled over a rotating drum to loosen compacted materials. They then flow onto a giant conveyer belt, which whisks the jumble into the main facility.

3 Manual pre-sort Teams of human sorters pick out non-recyclable items from the fast-moving stream, including crisp packets, plastic bags, shoes and nappies, as well as large items like scrap metal that might jam the machines.

4 Star screen sorting A series of vibrating, rotating shafts, fitted with offset star-shaped discs, lift large and light materials like cardboard upwards; smaller items like paper, bottles and cans fall through and continue on the conveyer belt.

5 Manual sort For a second time, teams of human sorters stand at intervals along the conveyer belt and look out for any smaller contaminants that might have snuck into the mix, such as personal electronics, trinkets, wallets and pieces of food.

6 Star screens round two A trio of finer-grained star screens sift out different grades of paper, which are directed towards dedicated storage units. Glass, metals and plastics fall through the screens again and continue on the conveyer belt.

"UK farmers add an average of 100 kilograms of nitrogen fertiliser to every hectare of arable land each year"

7 Glass sorter As they fall through the star screens, glass containers get crushed by the rotating stars. The fragments fall into bins below the screens, and are transported offsite to be sorted by colour and ground into coarse sand.

8 Steel magnet The remaining materials pass under a powerful rotating belt magnet, which lifts out tin and steel cans and drops them into a storage bunker. This usually only removes around four per cent of the recyclables passing through the plant.

9 Eddy current separator Since aluminium isn't magnetic, it is picked out using a strong reverse magnet called an eddy current separator. This uses spinning magnets to induce a current in the cans, which makes them fly off the belt and into a bunker.

10 Optical sorting with IR lasers Computerised scanners use infrared lasers to identify certain plastics by their optical properties. Once identified, an item will be thrust into a specific bunker by a directional burst of air.

11 Manual sorting The remaining plastics are carefully sorted by teams of workers. They also perform a last check, picking out and redirecting any recyclable items that have been missed by the mechanical processes and remain on the line.

12 Baler One at a time, the bunkers are opened, pouring out plastic, cans, metals or paper. Baling machines compress these into cubic bales ready to be taken to reprocessing plants for recycling. Any leftover materials at this point go to a landfill site.

Air pollution

With the potential to cross international boundaries, air pollution is a truly global problem

Air pollution is the introduction of gases and particles into the atmosphere that have harmful effects on living creatures and the built environment. According to the World Health Organiation, 7 million premature deaths are caused every year by people inhaling polluted air – that's one in eight deaths worldwide. Once released into the atmosphere, pollutants are impossible to contain and – depending on prevailing weather patterns – have the potential to affect people who are hundreds or even thousands of kilometres from the source.

Over the last half century, the nature of the problem has altered. In the developed world, smog-causing emissions of noxious smoke, sulphur dioxide and particulates associated with incomplete fuel combustion have been curbed by technologies like flue-gas desulphurisation systems, soot scrubbers and catalytic converters. Gases that deplete the stratospheric ozone layer most aggressively have been outlawed and replaced by safer compounds, and today it's the threat of global warming that looms largest.

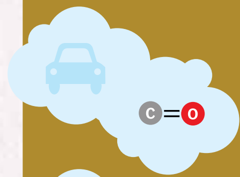
There is growing evidence, however, that respiratory problems like asthma might actually be caused by air pollution, not just triggered by it. Some researchers have even made tentative links between neighbourhood air quality and rates of childhood autism.

As with other forms of pollution, the best way to protect the environment is to avoid releasing these toxic elements in the first place. Conserving electricity, driving mindfully, and choosing to walk, cycle or take public transport are easy choices we can all make in order to breathe a little easier.

Beijing issued its first ever 'red alerts' for hazardous smog in December 2015

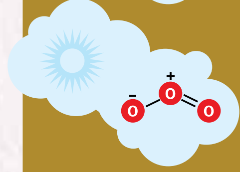
Atmospheric pollutants

The major contributors to environmental damage



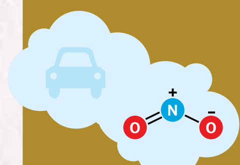
Carbon monoxide (CO)

This gas is produced when fossil fuels burn incompletely, with road vehicles being the predominant source.



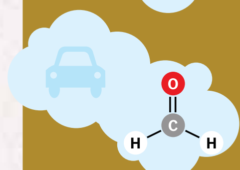
Ozone (O_3)

This is formed when other pollutants react in the presence of heat and sunlight. It triggers lung irritation and asthma attacks.



Nitrogen oxides (NO_x)

These form during fossil fuel combustion and contribute to global warming, smog and ground level ozone formation.

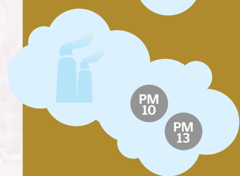


Volatile Organic Compounds (VOCs)

In the presence of pollutants, these carbon-based chemicals contribute to the formation of ground level ozone and smog.

Sulphur dioxide (SO_2)

This is produced during incomplete combustion in coal-fired power stations and fireplaces. It contributes to smog and acid rain.



Particulates

These include airborne dust, dirt, soot and smoke. They can cause respiratory problems and environmental damage, such as acidification of lakes.

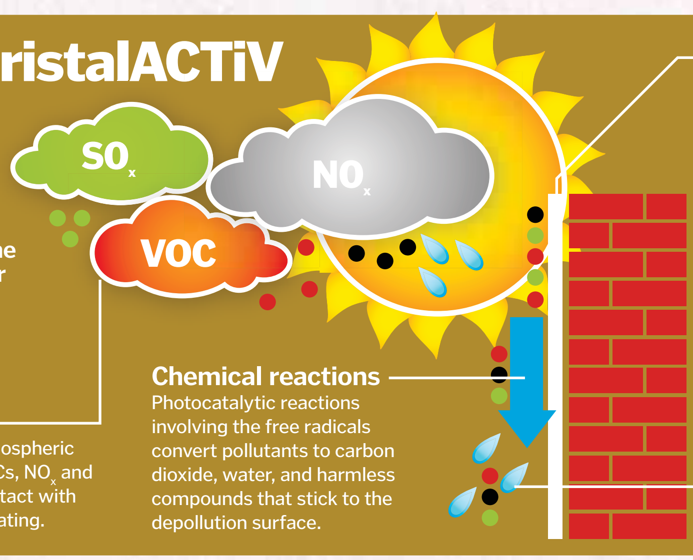
Photocatalysis

In some cases, airborne pollutants convert to harmless materials when they react chemically with other atmospheric gases. These reactions happen naturally in the presence of light, but on a slow timescale. In photocatalysis, the rate of these everyday reactions is boosted using a catalyst.

Innovative chemical company Cristal has pioneered a pollution-busting coating that can be painted directly onto buildings. Made from ultra-fine photocatalytic titanium dioxide (TiO_2), it actively draws pollutants including VOCs, NO_x and sulphur dioxides from the surrounding air and converts them into harmless by-products that are easily washed away. Best of all, the catalyst itself is not used up in the reaction, so its performance never dips.

How CristalACTiV works

This clever coating can be painted on structures to help cleanse the surrounding air



Depollution coating
Under the sun's UV light, the titanium dioxide (TiO_2) coating forms highly reactive free radical particles, capable of breaking down pollutants.

Pollutants
Photoreactive atmospheric pollutants like VOCs, NO_x and SO_x come into contact with the depollution coating.

Chemical reactions
Photocatalytic reactions involving the free radicals convert pollutants to carbon dioxide, water, and harmless compounds that stick to the depollution surface.

Self-cleaning surface
The soiled surface is washed clean whenever rain falls, or it is hosed down.

Ocean pollution

From oil and debris to sewage and toxic chemicals – our seas have it all

Oceans cover 71 per cent of our planet's surface and contain an estimated 1.5 million species, but that hasn't stopped humanity treating the sea as a giant, watery rubbish bin.

We're familiar with tragic images of seabirds whose feathers are clogged with viscous black oil. But catastrophic spills from tankers account for just a fraction of oil pollution in the sea; street runoff, vehicle exhausts and industrial waste are all chronic contributors to the problem.

Indeed, almost all marine pollution stems from activities on land. Runoff from farms introduces pesticides and insecticides into the aquatic food chain, as well as an overabundance of nutrients in the form of fertiliser. This causes populations of algae to spike, draining the surrounding waters of oxygen and suffocating other marine life.

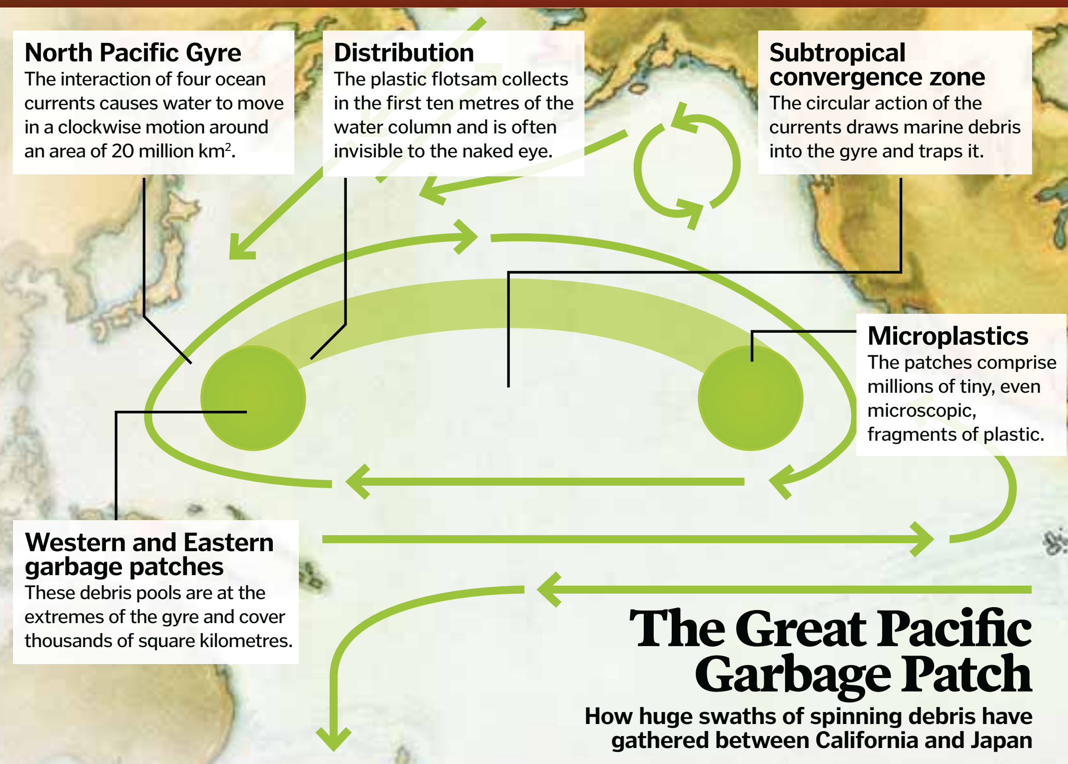
Finally, human-made rubbish is ubiquitous throughout the world's oceans, where it is corralled by currents into vast swirling 'garbage patches'. Many items, including fishing gear, glass, metal, paper, cloth and rubber, can take years, decades, or even centuries to decompose.

The worst offenders – plastics – essentially persist forever, but are broken down under the Sun's UV rays into ever smaller pieces. The eventual soup of 'microplastics' – invisible to the naked eye – poses a threat to wildlife that ingests it, and to the entire food chain due to the leaching of harmful chemicals.

> *"Almost all marine pollution stems from activities on land"*

There are no easy solutions, but a burst of new technologies may begin to turn the tide. In just 18 months, 'Mr Trash Wheel', a filtering water wheel with its own Twitter account, has removed over 400 tons of rubbish from Inner Harbor in Baltimore, US. Proposals for open ocean filtration systems include a solar-powered 'vacuum boat' called SeaVax, that its inventors claim will suck up 22,000 tons of garbage each year.

The most common items washed up on beaches include plastic bottles and cutlery, and coffee cup lids. The good news is that means we can help by making simple changes to our lifestyles, like carrying reusable water bottles and utensils.



The Great Pacific Garbage Patch

How huge swaths of spinning debris have gathered between California and Japan

Marine debris timeline

How long does common rubbish persist in the ocean?

Cigarette butt

The most common item found on beach clean-ups, making up 25 per cent of all collected debris. They contain a synthetic fibre that takes years to break down.

Aluminium can

An aluminium oxide coating makes aluminium cans very resistant to dissolving in sea water. Frustratingly, they are one of the simplest items to recycle.

Plastic drink bottle

Plastics degrade into tiny pieces, but they never fully disappear. Americans alone throw away over 35 billion plastic water bottles per year.

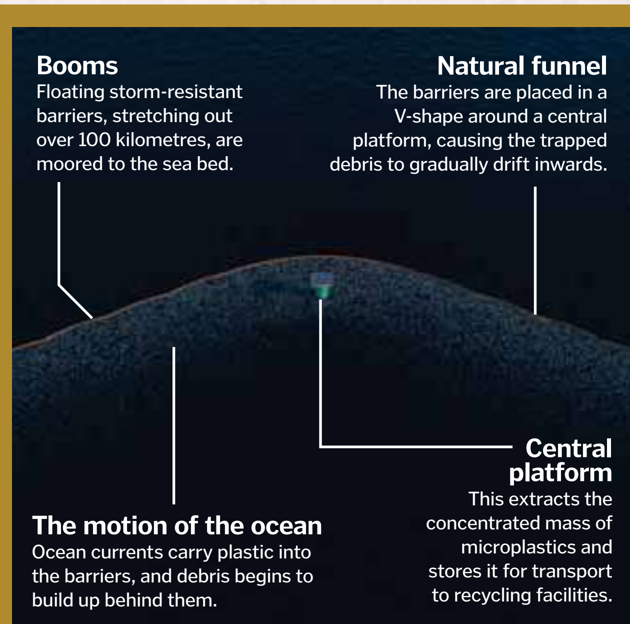
Disposable nappy

Nappies are made from multiple layers, including various long-lived plastics like polythene and polyester. They easily outlive the child that wears them.

The Ocean Cleanup Array

The brainchild of 21-year-old Dutch inventor Boyan Slat, the Ocean Cleanup Array harnesses ocean currents to sweep floating plastic debris into a gigantic 100-kilometre long collector for recycling. The innovative system comprises a pair of floating barriers, held in a V-shape, that skim tiny pieces of plastic flotsam from the oncoming currents while allowing sea life to pass safely underneath.

The crowdfunded project has the potential to remove over 7 million tons of microplastics from the world's oceans, and its creators claim that a single Ocean Cleanup Array could halve the size of the Great Pacific Garbage Patch (where the system is currently being tested) in just ten years.



HUMANITY'S GREATEST ACHIEVEMENTS

The past 100 years have seen some of the most species-defining achievements in our history

Words by **Laura Mears**

Landing on the Moon

The Space Race started with the Soviet Sputnik satellite in 1957 and ended when Neil Armstrong stepped on to the Moon in 1969. It was one of the most intense periods of technological and scientific advancement of the modern era, and it opened a gateway to the future.

Driven by the Cold War between the United States and the Soviet Union, and powered by rockets designed to carry nuclear warheads, the Space Race left a legacy far greater than a human footprint on another world. As a result of that period of invention, Earth has changed completely. We now live inside a cage of satellites that beam communications across the globe, monitor our weather, help us to navigate, and provide a stream of new information about the universe beyond.

Conquering infection

Vaccinations and antibiotics are two of the most significant medical breakthroughs ever. With these tools at our disposal, we can now prevent and treat deadly diseases that have threatened our species for centuries. In 1796, Edward Jenner invented the first vaccine, against smallpox, and Alexander Fleming discovered the first antibiotic, penicillin, in 1928. These discoveries, and the ones that followed, have saved millions upon millions of lives. In fact, vaccines have actually been so successful that we're starting to eradicate certain diseases completely. Smallpox hasn't infected anyone since 1978, and there were only 22 cases of polio worldwide in 2017.

Connecting the globe

People started connecting computers together during the Cold War, but it wasn't until Tim Berners-Lee created 'hypertext transfer protocol' in 1989 that the internet really began. Http lets computers find each other, making it possible to access all of human knowledge at the tap of a thumb.

"Quantum computers will answer questions that normal computers can't"

Sequencing the genome

It took more than 1,000 people 13 years to sequence the human genome. But once we'd worked out the order of the 3 billion DNA letters that make up our species' unique genetic code, everything changed. We can now compare our DNA to that of other animals to answer fundamental questions about how life works.

What next?

1 Building a space base
The next big step in space exploration is building a lunar outpost. Once we have a permanent human presence on the Moon, we can start thinking about Mars and beyond.

2 Controlling cancer
Finding cures for all types of cancer is one of humanity's biggest challenges, but we're getting closer. One day, medical advances will turn this deadly disease into a manageable illness.

3 Quantum computers
In the future, quantum computers will answer questions that normal computers can't. They solve problems differently, using superposition and entanglement instead of zeros and ones.

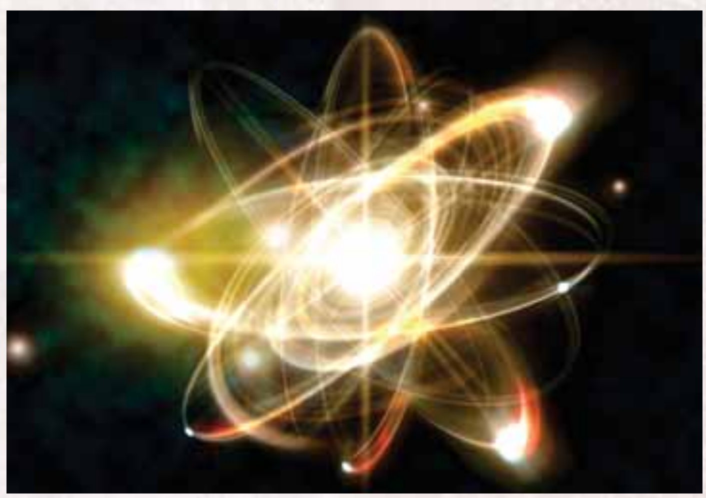
4 Fusion power
The Sun makes energy by fusing atomic nuclei. When we can master the same process on Earth, we'll unlock a powerful source of carbon-free energy.

5 Detecting dark matter
Together dark matter and dark energy make up 95 per cent of the universe, but we haven't managed to detect them yet. When we do, we'll be entering a new era of physics and astronomy.

"When we can master the process of nuclear fusion on Earth, we'll unlock a powerful source of carbon-free energy"

Splitting the atom

Until the early 1900s, we thought that atoms were the smallest particles that existed. Then, Ernest Rutherford broke one open. He discovered that if you fired neutrons at the atomic nucleus, it would split apart, releasing high-energy particles. This became the basis for nuclear power and the atomic bomb.

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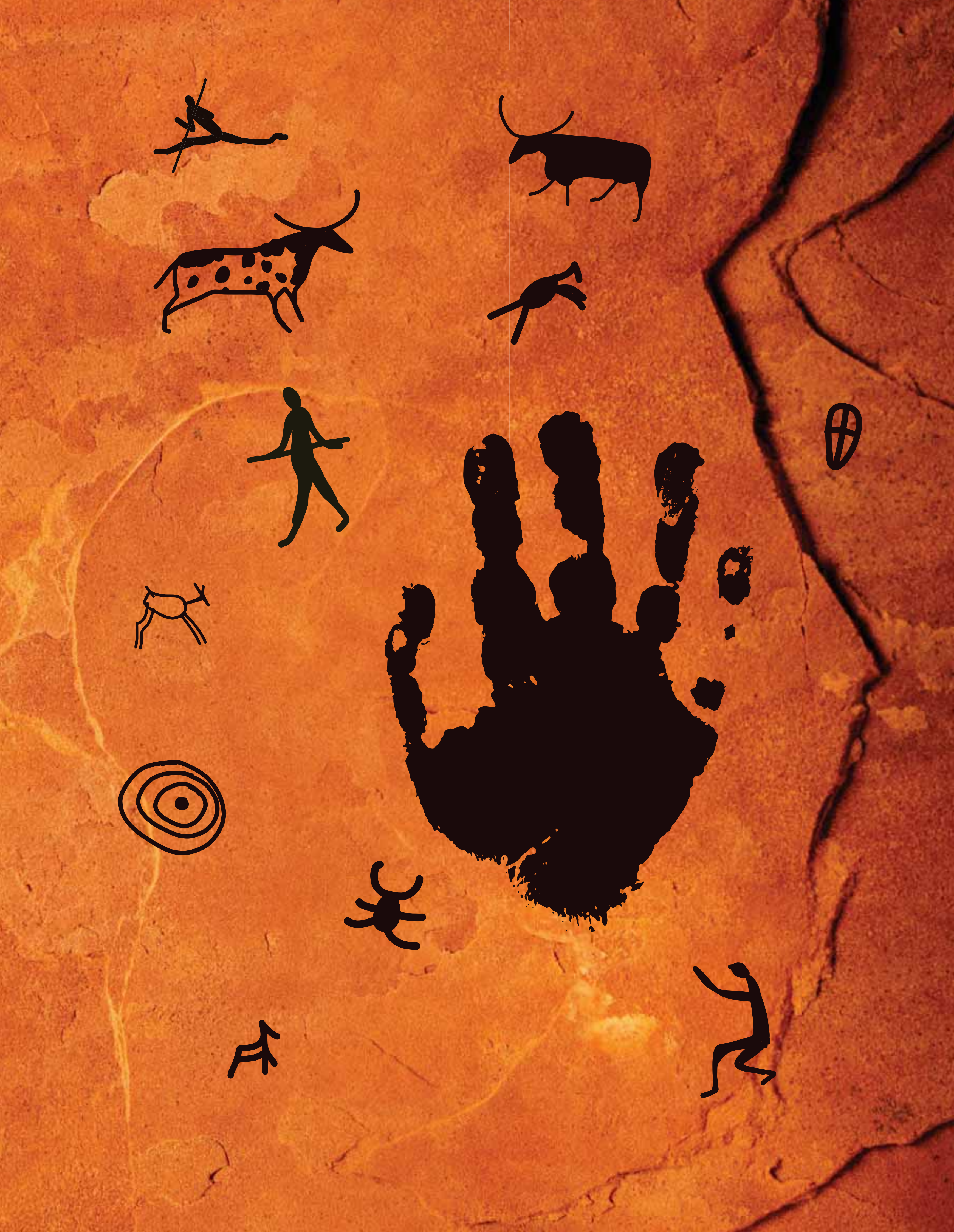

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OUR EVOLUTION

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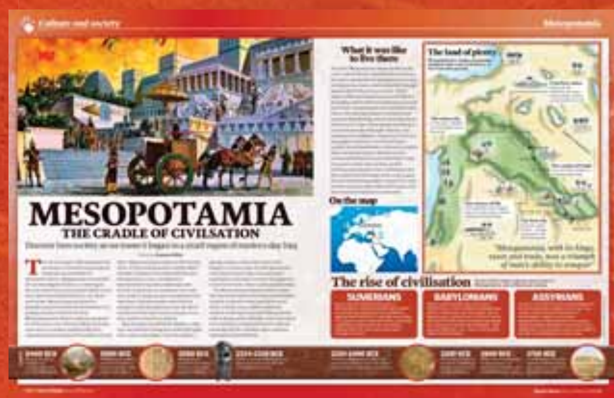

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